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SOME ASPECTS OF THE PRESENT SIGNIFICANCE OF NUTRITION.

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Twenty-three years ago the most frequently met among many slogans was "Food will Win the War." Today our food problems are fully as important to our defense; but they present many new aspects. Then our prime duty was to save food: now it is to consume food in the way most conducive to fitness.

Our knowledge of nutrition has advanced so rapidly that much of it is too new to have been assimilated into our everyday thought and practice. Yet it is precisely as guidance to everyday use of our familiar foods that the newest knowledge of nutrition can be of most benefit: of benefit *both* to the one-third of our people who are officially declared "ill-nourished," and to the great majority of the rest of us as well. For while finding that much of our previously baffling disease and frustration is due to shortage of certain nutritional factors in the food supply, research has also shown that a more scientifically guided use of our everyday foods constitutes a sort of superior chemical engineering of our own mechanisms which can increase the vitality and efficiency even of those people who are already healthy and efficient. The relations of nutrition to the functioning of the mind are, of course, more difficult of controlled investigation and not yet as objectively

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demonstrable as the effects of food upon bodily functions and length of life. But careful research is now showing that even within the range of fully normal conditions, our daily food choices have much more important effects than science ever previously supposed upon that internal chemistry that directly environs and conditions all our life processes. The blood is the great mediator of this internal environment, and the same blood circulates through the brain as through all the other organs of the body, bringing its help or its hindrance to both mental and muscular activities. True there is much which remains to be clarified by further research; but the already established findings, of recent and current nutritional investigation, need only to be more widely known and used in order to make our people much stronger for the defense of our civilization, and for its permanent advancement when the emergency has passed. In our "intellectual climate" of the moment there is still a good deal of inertia because the newest knowledge is not yet sufficiently understood, while at the same time the new view is perhaps being over-colored by some writers. This paper therefore does not seek to add more assertions; but rather to review objectively the evidence on what the Council of National Defense has announced as one of our present-day needs, "to make the American people nutrition-conscious in terms of the nutritional science of today."

THE MAJOR ASPECTS OF NUTRITION.

Nutrition presents three major aspects: (1) that in which food serves as fuel to supply energy for the activities of the bodily machine; (2) that of the assimilation of certain food constituents into structural material first for the growth and later for the upkeep of the body tissues; and (3) the utilization of food substances either directly or indirectly to serve the body in those self-regulatory processes by which it maintains its relatively "steady states" or essential internal environment.

STATUS OF THE ENERGY ASPECT.

It is in its energy aspect that nutrition has most fully arrived at the status of an exact science.[1] Expert opinion is

[1] Even with a title which absolves from any effort at completeness, the writer finds this paper so severe an exercise in conciseness that he has been obliged to forego all specific mention of our indebtedness to individuals.

well agreed on the fundamental principles of the energy transformations in the body, on the values of the foodstuffs as sources of energy, and on at least the broad lines of theory as to the influence of different bodily conditions in determining the energy need. On the latter points, especially, many laboratories are actively engaged in increasing the precision of present knowledge, and at least three well-endowed nutrition laboratories—those of the Carnegie Institution, of the Russell Sage Institute, and of the Rochester University Department of Vital Economics—are devoting their resources especially to the perfection of the energy aspects of nutritional knowledge.

NUTRITIONAL SIGNIFICANCE OF THE PROTEINS AND THEIR AMINO ACIDS.

The protein aspect of nutritional research has also reached a relatively mature status with well-defined objectives. Among many other laboratories working in this field, that of the United States Department of Agriculture is giving special attention to the purification and description of the proteins themselves; and the laboratory of physiological chemistry of the University of Illinois is very actively investigating the nutritional relationships of the individual amino acids, with the generous support of the Rockefeller Foundation. We may look forward with confidence and great gratification to a presumably fairly near future in which this aspect of nutritional need can be stated quantitatively in terms of ten individually indispensable amino acids.

ENZYMES AND COENZYMES.

The catalysts which make the chemical processes in the body go fast enough to support life overlap and in a measure integrate the subject matter divisions of the chemistry of nutrition. They function in the energy aspect; and in their own chemical constitutions they are derivatives of proteins (or their amino acids), mineral elements, and vitamins. This very active field of research is quite as frequently classified with general biochemistry as with nutrition.

MINERAL ELEMENTS AND VITAMINS.

Until its current era of "newer knowledge," the chemistry of food and nutrition had for several decades faced the

dilemma that foods could be analyzed as elaborately, and their composition accounted for with as close an approach to one hundred per cent., as other natural materials; and yet nutrition could not be sustained with pure mixtures of the substances that the analyses revealed.

Seeking deeper insights, chemists broadened their research methods to include the systematic use of feeding experiments with laboratory animals, carried on with as careful attention to accuracy of controls as in other experimental researches in the exact sciences.

This extension of method in chemical research has been rewarded with a rapid series of discoveries of substances which are essential to our nutrition, but whose very existence was, until recent years, either entirely unknown or only vaguely apprehended.

Neither in chemical nature nor in nutritional function do these substances have much in common with each other. That they came to be called by the group name *vitamins* was not the result of their being naturally related, but rather of the two circumstances, (1) that they were all discovered through the use of the same development of research method, and (2) that the discoveries of their existence and importance followed each other too rapidly for physical isolation and chemical identification and nomenclature to keep pace. The latter, however, are steadily catching up, and in several cases new names, which are individually distinctive of either the chemical structures or the historic associations of the substances, have been coined and are coming into general use.

QUALITATIVE SIGNIFICANCES OF A FEW OF THESE NEW FACTORS.

Vitamin A has been found to occur both as such and in the form of several precursors, and rather than try to coin one word to cover several substances we continue to use the alphabetical designation, with or without mention of precursors, or we say *vitamin A value*. In addition to its many other functions in our bodies, vitamin A has been found to be immediately essential to *vision*, a fact effectively used in the introductory summary of the Federal volume "Food and Life."

Vitamin B has been differentiated into thiamin, riboflavin, nicotinic acid, pantothenic acid, and pyridoxine, all now

structurally identified, while still other possibilities are under investigation. *Thiamin* prevents and cures some of the most prevalent of the nerve diseases both of the Orient and of our Western World; and as it aids a fundamental intermediate step in the nutritional chemistry of all of our organs and tissues, it is proving helpful in a surprising diversity of ills. *Nicotinic acid*—a substance *not* nutritionally related to nicotine, and until lately little more than a laboratory curiosity—has been found dramatically potent in the cure of the conspicuous inflammation of the skin (and tongue) which gives the name to the disease *pellagra* which has been extremely prevalent in our Southern States; and which may perhaps afflict other regions and other countries to a larger extent than is recognized. Few discoveries could be more striking than that of the potency of this simple and inexpensive substance in the prevention and cure of such a scourge as pellagra. Yet it remains to be said that when the typical pellagrin has been cured of his pellagra by means of nicotinic acid alone, he needs something more to make him a fully healthy man. The previous diet of the poor pellagrin has usually contained so little of foods other than grain products, fats, and sweets as to make his bodily condition that of a *multiple* nutritional deficiency instead of a "single" or "simple" one. Clinical treatment with the pure vitamins, separately and in combination, shows that the typical pellagrin probably needs *riboflavin* almost as much as he needs nicotinic acid, and often needs thiamin also, while in only less degree his "one-sided" food supply is likely to have involved other shortages as well as these three. Good diet cures all of these deficiencies at once, and renders unnecessary the further investigation of the frequency in the pellagrous population of shortages other than those of nicotinic acid, riboflavin, and thiamin. It is believed that if these three vitamins were regularly and adequately added to white flour and to the corresponding products of corn, illness would be reduced and the efficiency of our people improved; while there would still be a higher goal ahead to be reached through better understanding and appreciation of what constitutes a well balanced dietary or food supply, and what it can do for one's health and efficiency.

In the case of the *antiscorbutic vitamin* the new world has done much to repay its debt to Europe. The old world got the potato from the new, and with year-round availability of potatoes scurvy became relatively rare. Also, it was an American physician who first clearly set forth the view that the antiscorbutic property of "fresh" food is due to a *definite substance;* and an American chemist who first identified this substance now called interchangeably *ascorbic acid* or *vitamin C.*

Another of this rapid series of discoveries was the finding of a vitamin since differentiated into several, *the vitamins D,* preventive of rickets which had recently been called the most prevalent of all diseases outside of the tropics.

Any one of such discoveries of nutritional means for the cure and prevention of previously baffling diseases might alone have made this generation memorable in the history of the medical sciences and of human progress.

Not only did these discoveries open men's eyes to a broader and clearer view of their ills: that not every disease is to be explained in terms of the presence of something injurious, because several are now seen to be due (instead) to a lack or shortage of something nutritionally essential. In addition, these discoveries led to a further and more constructive advance.

QUANTITATIVE ASPECTS OF THE NEWER PROBLEMS.

Even while the chemical identification of the earlier-discovered of the vitamins was still in progress, means of measuring them through their effects had been worked out and much active and fruitful research was in progress upon such quantitative problems as, In what relative abundance do these substances occur in different types of foods and elsewhere in nature?, How much is required in nutrition under different conditions?, and How liberal a nutritional intake of each yields *best* results in the long view which considers the whole lifetime and successive generations?

Laboratory research upon problems of amounts or proportions of nutritional intakes has also gained much through the clear recognition of the scientific value of the use of two kinds of experimental variable: (1) the individual chemical

factor; and (2) the actual article of food as produced by nature or agriculture and consumed in everyday life.

ADEQUATE VERSUS OPTIMAL NUTRITION.

The chairman of the League of Nations' mixed committee on nutrition reduced the problem of food supply to its simplest terms when he said that what is needed is, "Not only enough food but also enough of the *right kinds* of food." In the nature of things the "protective" foods must usually be more expensive, calorie-for-calorie, than the more abundant "fuel" foods such as the chief grain crops. Thus for most low-income families at all times, and for greater proportions of the people during food shortages such as accompanied and followed the first World War, and now threatens the world again, a persistently outstanding problem is, What proportion of protective food is needed so to "balance" a dietary or food supply as to permit the full development and exercise of the innate capacities of those subsisting upon it? Twenty years of experimentation in the field that this question suggests, with large numbers of laboratory animals continued throughout the entire lifetimes of successive generations under the standards of control characteristic of research in the exact sciences, have brought accurately measured objective evidence that there is an important distinction between the merely adequate and the optimal in nutrition; and that the difference between the minimal-adequate and the optimal levels is much greater for some nutritional factors than for others.

Perhaps it should be said that optimal nutrition is an ultimate goal which science is not yet prepared to define descriptively in detail.

Speaking operationally, we may say that recent research has established, fully and objectively, the *principle* of the nutritional improvability of the normal. The experimental evidence can, of course, be but sketchily presented in a review of this sort which attempts to summarize in so little space a scientific advance of undoubtedly far-reaching significance. Under the necessity of extreme brevity, the writer trusts he will be pardoned for drawing illustrations chiefly from the work with which he is best acquainted.

In experiments to determine what proportion of protective food suffices to balance a maximum proportion of wheat in the diet, it was found that a mixture of five-sixths ground whole wheat and one-sixth dried whole milk with table salt and distilled water (*Diet A*) was *adequate* in that it supported normal growth and health with successful reproduction and rearing of young, generation after generation. Yet when the proportion of milk was increased (*Diet B*) the average results were *better*.

NUTRITIONAL IMPROVEMENT OF THE NORMAL LIFE HISTORY.

In the experiments just mentioned, an already-adequate dietary and an already-normal condition of nutritional wellbeing and health were improved by a more scientific adjustment of the relative quantities in which the staple articles of food were consumed. And in the comparison of the effects of these two diets the principle of the nutritional improvability of the normal was manifested measurably at every stage of the life cycle. Growth and development, adult vitality, and length of life all were normal on Diet A and all were better on Diet B.

This research having been planned in terms of natural articles of food, the sole experimental variable was the quantitative proportion or ratio between the foods constituting the dietary. If, on the other hand, we turn to the consideration of individual chemical factors, we find that the single change in proportions of staple foods had the effect of enriching the dietary at four points: protein, calcium, riboflavin, and vitamin A.

Subsequent experimentation was planned both in terms of these four chemical factors separately and in terms of diversification of the dietary by addition of natural foods of other types. Here it was found that enrichment of the original diet with protein alone or its diversification with other natural foods tended to a moderate increase in growth and adult size, but no distinct improvement in the life history. Clearly this indicates that the increased intake of protein played but little if any part in the nutritional improvement induced by Diet B over Diet A; and also strengthens the probability that the observed improvement is essentially explainable in terms of

the factors we recognize, for if anything unknown had played an important rôle in this improvement, the diversification of the diet would probably have revealed some indication of it.

Calcium, riboflavin, and vitamin A each is found to play a significant part in the nutritional improvement of the already adequate diet and already normal health. With each of these three factors the level of intake giving *best* results in long-term experiments is two or more times higher than the level of *minimal* adequacy. Some aspects of the respective rôles of these three factors are still subjects of further experimental investigation.

OTHER NUTRITIONAL FACTORS SHOULD BE SIMILARLY STUDIED.

It is not to be assumed that the wide margins of beneficial intake over actual need, found as just mentioned with calcium, riboflavin, and vitamin A, will apply to the other nutritionally essential mineral elements and vitamins. Each should be investigated independently in this respect; and with no presuppositions derived from the findings with calcium, riboflavin, and vitamin A, for these were not random samples, but were taken for rigorous experimental study because of the definite suggestions of earlier work.

Meanwhile the above-mentioned findings with the factors already comprehensively investigated afford a basis both for clarification of a fundamental chemical principle in nutrition, and for its practical application.

CHEMICAL ASPECT OF THE BODY'S INTERNAL ENVIRONMENT.

One useful first-approximation of nineteenth-century science was that an organism may be expected to grow only as fast or as far as is consistent with the specific chemical composition of its kind; and another was that it is the *fixité* of the organism's internal environment which enables it to cope with new or changing external environments. It is surprising that these views continued to be held so rigidly for so long when at the same time there were developing physico-chemical principles which call for a more flexible concept. In this light it seems clear that the so-called steady states of the body are only relatively so: that one cannot introduce into the system different amounts and proportions of such active factors as we

know some food constituents to be, without some resulting changes of concentration levels or of dynamic-equilibrium points, or both. And now we have the objective evidence of well-controlled, long-term experimentation showing nutritional improvement of an already normal bodily condition in such manner as seems best expressed by saying that the chemical aspect of the body's internal environment has been modified for the better. Thus in accordance with physico-chemical principles, we now conceive the "normal level" of each nutritional factor to be not a single fixed level but a *zone*. Undoubtedly this zone is wider for some factors than for others, and probably also the most advantageous level is with some substances near the upper margins, and with other substances near the middle or the lower margins, of the respective normal zones. Thus while our bodies enjoy by virtue of their biological inheritance certain self-regulatory processes of striking effectiveness, our minds are now finding, through chemical research, how these can be made still more effective by the scientific guidance of our nutritional intakes; by helpfully influencing our internal environments through good habits in our daily choice of food.

Contemporary research in the chemistry of nutrition is here developing a fundamental and far-reaching scientific concept which hitherto has hardly been apprehended because species have been regarded as more rigidly specific in their chemical composition, and the "steady states" of their internal environment have been regarded as more rigidly fixed, than they really are.

The accepted generalization that each life history is determined (1) by heredity and (2) by environment assigns all except hereditary factors to environment by definition. But as the result of nearly a century of scientific as well as popular habit of thought, the word "environment" actually connotes surroundings. Science exaggerated the extent and rigidity with which our internal chemistry is automatically regulated by our biological inheritance, to such an extent that there seemed nothing for us to do about it except to admire its wonders and stand ready to repair its occasional breakdowns. But now that we are finding ways to add conscious chemical control and improvement to the marvelous mechanism with

which nature endows us, we can be not merely repair-men to a biologically inherited bodily machine, but also architects of a higher health.

It may help to make this newly-opened opportunity clearer if, instead of the above-mentioned two, we think and speak of *three* major determinants of our life-histories: (1) ***heredity;*** (2) environment, in the familiar external sense of ***surroundings;*** and (3) the body's ***internal environment,*** which immediately environs and conditions the life process, and which in the course of the life cycle is much more significantly influenced than hitherto supposed by even the normal differences in what we take into our bodies as food.

This responsiveness of our internal chemistry, and resulting degree or level of positive health, to our nutritional intake, usually becomes manifestly measurable only in cases of visible injury from nutritional deficiency, which, once apprehended, we seek to avoid; or in experimentation with laboratory animals whose natural life-cycles are such as to permit of accurately controlled conditions and observations extending throughout entire lifetimes and successive generations.

In the long-controlled, laboratory-bred colony of experimental animals used in large numbers for full-life and successive-generation feeding tests conducted with all the quantitatively meticulous care and precautions to which research workers in the exact sciences are trained, we now have an instrument and technique of investigation such as has not existed before.

Much remains to be done in the new field of research thus opened; but work already completed shows clearly the possibility of nutritional improvements of already-normal health, vitality, and efficiency throughout our lives. Whatever we are individually born with, we can each do more for ourselves to influence our life histories in the direction of our aspirations than science has hitherto thought.

Starting at such a nutritional and health level as probably most people accept as their norm, it is now clearly possible (1) better to ensure a normally prompt development of the young, (2) to induce a higher level of adult vitality and accomplishment, and (3) materially to improve the duration as

well as the quality of life, through the guidance of nutritional knowledge in the everyday choice and use of food.

SOME QUESTIONS ANSWERED AND SOME OPEN.

Three questions may have suggested themselves: (1) How conclusive are the data supporting such statements as those of the preceding paragraph?; (2) What are the grounds for confidence in the human application of the findings of laboratory animal experimentation in this field?; and (3) With all due reverence for individual human lives, will a longer-lived population be an advantage? Each of these questions is worthy of a much fuller answer than the space here available permits; and could be answered with much ampler evidence and explanation, but for the present need of extreme condensation.

Statistical analysis of the objective, numerically recorded data of laboratory-controlled experiments shows, at all stages of the life cycle, nutritional improvements upon the initial norms with measured differences so manyfold greater than their probable errors as to establish these findings with higher degrees of scientific certainty than probably attach to most of the unquestioned facts of physiology. The least-expected of the new findings, namely, the extension of the normal adult life-expectation, is objectively established with 100-fold greater degree of statistical convincingness than the accepted canons of scientific criticism call for to justify the characterization of such a finding as "undoubted."

The basal dietary of these experiments is representative of the food supplies upon which a large proportion of our people subsist; and the animal species chiefly used for the full-life, successive-generation experiments above mentioned is the rat, chosen primarily because of the many and close resemblances of the chemistry of the nutrition of that species and our own. The only known significant differences are with respect to ascorbic and nicotinic acids; and toward both of these the human species is much more responsive to the level of dietary intake than is the rat. Critical study reveals no reason to discount the above-noted laboratory findings because of species difference; but, on the contrary, shows strong scientific evidence that the indications obtained from the experiments

with rats are *well within* the probabilities of the nutritional improvement of human lives by intelligent use of our everyday foods.

Such nutritional improvement results not only in longer life but also in the living of our lives upon a higher level of health and accomplishment *throughout*. The "extra time" is *not* added to the period of senility. It is inserted in the period of the prime, making this a longer fraction of the life cycle. Thus the nutritional improvement brings, to speak in human terms, both a larger number and a larger percentage of years of full accomplishment, and economic and social value, with a smaller proportion of years of dependency. Space does not permit the discussion here of the very real advantages, to the individual, to the world of industrial affairs, and to the nation, of an earlier attainment of full capacity and also a postponement of the onset of old age.

How to extend the benefits, of the newer knowledge of nutrition, as widely and as promptly as possible is both an economic and an educational problem. If space permitted, an abundance of statistical evidence could be assembled to show: (1) that, independently of educational opportunities, the families with better per capita purchasing power tend to provide themselves with nutritionally better food supplies; and (2) that also, among families exercising the same purchasing power in the same markets, some provide themselves with dietaries which are nutritionally excellent, others only good, and still others only fair.

Much can be (and in many places is being) gained *either* by direct economic measures to increase the purchasing power of low-income families whether by increase of money income or by making available to them larger supplies of protective foods at lower prices; *or* by widespread teaching of the nutritive values of foods and the influence of nutritional wellbeing upon health and earning-power. Needless to say, the communities which have good use of *both* of these means of improvement may expect to reap the largest benefit.

In an unbiased economic view everyone can see that there is opportunity for enormous benefit in using the new knowledge of nutritive values to guide the investment of the many billions of dollars that are annually spent in this country for

food; and especially when the choice of food is now known to have greater and more far-reaching effects upon health and earning power than has hitherto been supposed.

But how often bias enters to cloud the economic view! Attempts to teach a more scientific investment of money in food are apt to meet a "vested interest" attitude of resentment from many purveyors of things which science cannot recommend for a higher place in consumers' budgets. And perhaps an even larger number of people "object on principle to," or subconsciously react against, any attempt to teach discrimination of consumer demand, and any form of governmental paternalism or further extension of "government into business." In addition to all the bias of an economic or political sort, tradition in itself retards change, especially in matters which come so closely home as does the family food supply. And in the domain of food, as one of the wisest students of nutrition has said, tradition tends to accumulate prejudices quite as often as truths.

These and other causes tend somewhat unduly to caution in public teaching of the everyday use of the newer knowledge, which in terms of foods as bought and eaten is: Give fruits, vegetables, and milk in its various forms (including cheese, cream, and ice-cream, if desired) a larger place in the dietary and food budget. This can be done without "cutting out," and without too drastically "cutting down," any other article of food. As the Nestor of the newer knowledge of nutrition has consistently taught: If we eat what we should, we can at the same time eat what we like.

Another question sometimes arising is, How can we feel confident of the practical application of present nutritional knowledge when we admit its probable incompleteness by recommending further research? The present writer's answer is, that *some findings* of such far-reaching importance that their everyday application ought not to be postponed *are conclusively established*, and the practical advice above suggested is based upon these and is permanently valid. More elaborate and detailed dietary recommendations may well await the findings of such further researches as are briefly suggested below.

WHAT NEXT IN NUTRITION?

Both further research and fuller application, neither delayed by waiting upon the other, should be strongly emphasized, especially in view of the present and impending situation.

There should be prompt and wide dissemination of present knowledge at all teaching levels. And nothing is so stimulating to education as that research in the same field be actively productive at the same time. The best way to get a hearing, even for the findings now conclusively established, is to have some related new findings to tell.

If made in large numbers, with great care, and on a comprehensive plan, further researches with natural foods as the experimental variables might be of great value.

More accurate knowledge of the quantitative distribution of certain of the mineral elements and vitamins in foods can be sought with greater assurance of clear-cut findings, and with certainty that these data will function both in the advancement of science and in the service of human welfare.

There is also a field for much valuable research in the measurement of the nutritional availabilities of the mineral and other nutrients of the different articles and types of food more especially by experimental methods which comply with the actual conditions of normal nutrition.

With more precise knowledge of the nutritive values of a wider range of foods, it becomes increasingly practicable to ensure excellence of nutrition without sacrifice either of personal preferences in food selection or of the economic advantages which market fluctuations and seasonal conditions offer. Fortunately, most seasonal food crops are at their best when they are also at their cheapest.

The fuller our knowledge of nutrition, the less we *need depend* upon diversification, but the better we are prepared to gratify a taste for it. The newer knowledge of nutrition is friendly to the fact that "eating has a great vogue as an amusement," and several foods formerly regarded as luxuries are now seen to be good nutritional investments. The science of nutrition does *not* seek the sanctification of spinach: it looks with much more favor on many of the things that we find most fun in eating.

The new knowledge helps in meeting the problems of both war-time and peace-time food supplies; and the findings of further research will doubtless help us all still further to harmonize our appetites and aspirations—to know how to eat both what we want and what will make us most efficient.

FURTHER OPPORTUNITIES FOR FRUITFUL RESEARCH WITH SPECIAL REFERENCE TO THE NEEDS OF THE IMPENDING SITUATION.

Both for completeness of scientific explanation and to establish the boundaries of advantageous practical application of the findings, further research is needed even upon two of the three factors which, as mentioned in an earlier section, have already been studied more fully than others by our recently developed methods. As opportunity permits, similar studies should also be made of the long-time effects of different levels of intake of each nutritionally essential amino acid, mineral element, and vitamin. Meanwhile, the factors which have already been found to be of outstanding importance in experiments upon the entire life cycle should now be studied by similar methods but with starting-points at different ages so as to ascertain the *influence of initial age* upon the potentialities for nutritional improvement of the life history.

In the planning of all such studies the world-wide present interest in efficiency and preparedness will tend to give priority to those researches which bear most directly upon problems of the attainment of the fullest fitness, from whatever initial age, and the maintenance of optimal capacity for service. Fortunately, such advances of knowledge will serve both science and the nation well, however long or short the War, and whatever its aftermath may be.

Studies in nutritional rehabilitation deserve also a well-considered place in the general program for bringing the new knowledge into the service of all the people. Between the obvious cases of specific deficiency diseases and, on the other hand, the people whose physique and efficiency are within the zone of our present norm, too many even of our American people (and doubtless a higher proportion in most other countries) are handicapped though we may not know exactly how and why. Many of these people can be rescued from individual and family frustration, and incalculably enhanced

in economic and social value to the community and nation, by "enough of the *right kinds* of food"; and just what this means in more precise terms, how the greatest good can be accomplished with most promptness and efficiency, are problems within the scope of the present-day methods of research in the chemistry of nutrition.

Moreover, the same general type of research reveals good scientific probabilities of improving the chemistry of the internal environment, and thus enhancing the efficiency, of people who are already quite fortunately healthy and efficient.

Power Plants Take to Wheels and Water.—(*Electric Light and Power*, Vol. 18, No. 12.) Recent developments have stressed the need for mobile generating equipment particularly for emergency conditions where industrial production may be delayed through lack of electric power supply. Such conditions may be expected to arise from damage to power plants or transmission lines as a result of sabotage or other activities. Such equipment could also serve in a number of ways in a normal power system development, as for handling loads which are expected to be temporary. Design details of such units have been worked out. They range in size from 100 h.p. for single diesel units, two of which may be placed on one ordinary flat car to a 50,000 kva. steam electric unit designed for installation on a barge to be built to specification for the purpose. Steam electric units of 5,000 kva. and 10,000 kva. have also been designed for installation on railway flat cars, being designed to fit the limited space available. A complete report on the steam electric units for both flat car and barge installation was presented at the Wisconsin Utilities Association Meeting by A. P. KELLOGG of the Turbine Division of General Electric Co. With regard to car installations Mr. Kellogg said: "Such a power plant would be like the steam electric locomotive power plant in many ways. The boiler and auxiliaries would be similar but, of course, the turbine generator unit would be entirely different. The turbine and generator would be direct-connected at 3600 r.p.m. and the generator would deliver 60 cycle current. . . . Efficiency would not be high when compared with modern central stations, probably in the order of one pound of oil per kw.-hr. However, this compares favorably with many old units and is high enough to permit economical use for temporary or emergency loads. The ability to carry a load at some particular location for a few weeks would be of great value to a power system."

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VISIBILITY AND SEEING.

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SYNOPSIS.

Visibility is defined as an attribute of the physical characteristics of the object of regard as determined introspectively by an observer possessing normal vision. Therefore seeing may be defined as a function of the visibility of the object and the visual efficiency of the observer. Techniques for the appraisal of visual efficiency have long been available to visual science; and techniques for the appraisal of visibility are needed in illuminating engineering and throughout all practices involving seeing. The significance of visibility, as a factor in seeing, is presented through the medium of correlations with certain psychophysiological effects resulting from seeing under conditions which afford various degrees of visibility. These analyses reveal that visibility and ease of seeing are closely related. The frequency of involuntary blinking has been developed as a criterion of ease of seeing and correlated with measurements of visibility. By these correlations, visibility measurements become of the utmost importance in the science of seeing whose most important objectives involve measurements and interpretations in the realm of supra-threshold seeing.

I. FUNDAMENTAL CONSIDERATIONS.

Visibility.—Throughout this discussion, the term "visibility" is used to denote a quantitative measure of visual sensation and perception as a function of one or more physical variables of the threshold stimulus. In previous usage, this term denoted a property assigned to radiant energy within a certain range of wavelengths by reason of its power to excite a visual receptor process, or to evoke the introspective phenomenon of brightness.[1] Since the term *luminosity* has been substituted for the term *visibility*,[2] the latter is now available for use in the science of seeing from a less restricted viewpoint. In general, it is convenient to define visibility as an attribute of the object of regard. Thus the visibility of a given object is a function of variables such as its size and configuration, its

[1] "Dictionary of Psychology," W. C. Warren, Houghton Mifflin Co., New York, 1934.

[2] "Terms Used in Radiation Measurements," *Rev. Sci. Inst.*, 7, 1936, 322.

contrast with its background, the brightness of the object (or its background), the duration of the image on the retina and other factors which may be related to its perception and recognition.

It will be noted that this concept of visibility does not involve the ocular and perceptual characteristics of the observer as variables. Obviously, a consideration of these factors in the measurement of visibility would result in endless confusion. Therefore, it seems advisable to consider the attribute of visibility as representing an introspective integration of all relevant physical factors by an observer possessing normal vision and responses. Although the former characteristic may be considered as somewhat ambiguous by the ophthalmologist and the latter as undefinable by the psychologist, these characteristics of normalcy may be defined adequately for the limited significance which will be attached to them by the illuminating engineer. Thus for the practical purposes of the lighting art, the human variables may be summarized and expressed by the term "visual efficiency." Hence seeing may be considered as a function of the visibility of the object or objects of regard and the visual efficiency of the observer. It will be shown later that both visibility and visual efficiency may be appraised quantitatively by identical techniques.

Since the visibility of an object has been defined as a function of its physical characteristics, it follows as a theoretical possibility that the relative visibilities of a number of different objects might be determined from their physical characteristics and from the fundamental relationships established by physiological optics which are related to the variables of the visual stimulus. For this purpose, the relationships among the factors of size, contrast, brightness and duration are available.[3] However, even if it is conceded that these are the primarily important factors involved in visual discrimination, it should be obvious that the relative visibilities of only the simplest of objects could be determined by computation. In general, it may be stated that the influence of all of the variables associated with most objects can be integrated only

[3] "The Four Variables of the Visual Threshold," P. W. Cobb and Frank K. Moss, JOUR. FRANK. INST., 205, 1928, 831.

within the visual centers of the brain and, as far as measurements are concerned, only then under threshold conditions. Since the link of introspection is necessarily a part of any chain of involvements between the physical object and its recognition, it is recommended that this process be applied to the actual object of regard.

These considerations have led us to emphasize the need for, and the value of, techniques and instruments which will facilitate the appraisal of the visibility of an object or a visual task under the actual conditions which occur in practice.[4] Furthermore, it is often desirable to ascertain the degree of visibility which will be obtained by those persons who are to perform the visual task. Such techniques have long been available and used in the clinical practice of appraising visual efficiency. They are also needed in lighting practice or illuminating engineering. It is for these reasons that we developed and have made available the Luckiesh-Moss Visibility Meter [5]—a physical instrument which aids in the introspective determination of the visibility of any object viewed by any observer under any condition. Although this instrument was developed primarily for research purposes, it has been demonstrated conclusively that it may be applied in practice to a wide variety of visual problems.

II. THE MEASUREMENT OF VISIBILITY.

It should be recognized that the measurement of visibility involves not only several possible parameters for expressing this attribute of a given visual object or task under given conditions but also several variables by which threshold conditions may be attained in the measurement of visibility. For example, let us assume that the relative visibilities of several objects are to be determined by varying (1) their visual size, (2) the level of illumination upon them, or (3) the contrasts between the objects and their respective backgrounds. Each of these techniques inherently involves the attainment of threshold conditions and the possibility of expressing the

[4] "Visibility—Its Measurement and Significance in Seeing," Matthew Luckiesh and Frank K. Moss, JOUR. FRANK. INST., 220, 1935, 431.

[5] "The Science of Seeing," Matthew Luckiesh and Frank K. Moss, D. Van Nostrand Co., New York, 1937.

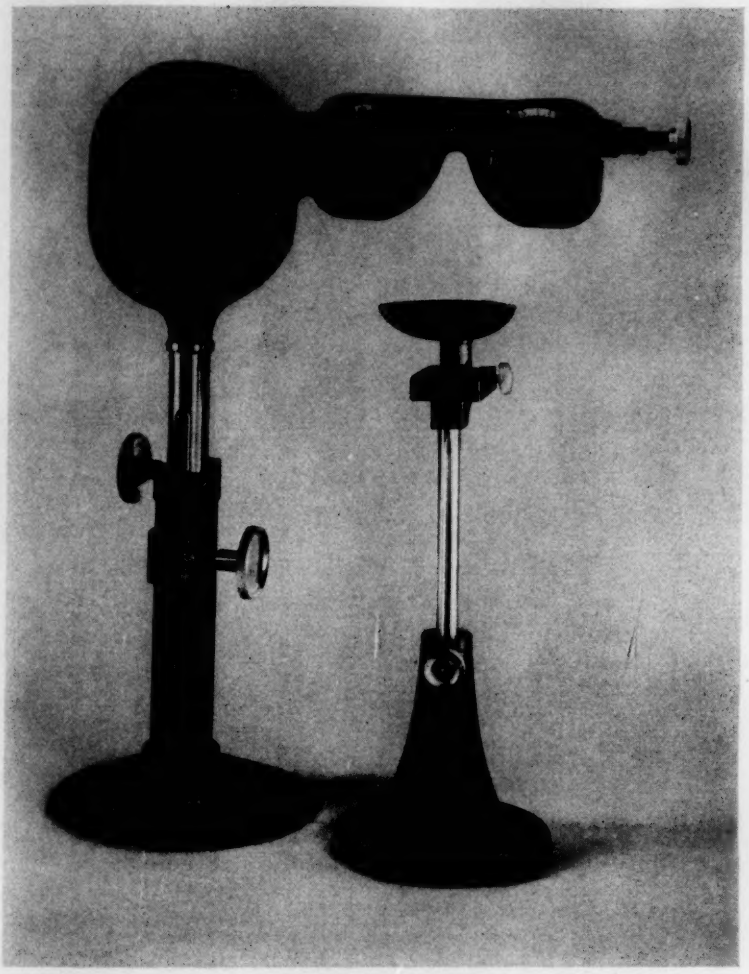
visibilities of the objects in terms of any one of the several fundamental variables of the visual threshold. In ophthalmology, the visual threshold is approached by successive reductions in the size of the characters of the acuity test-chart and the visual efficiency of the patient is correlated with the size of the threshold object. In the case of our visibility meter, the visual threshold is approached by progressive reductions in both the brightness and brightness-contrast characteristics of the object of regard and the visibility of the latter is expressed, as in ophthalmology, as a function of the threshold size of a standard object of equivalent visibility.

The L–M Visibility Meter is illustrated in Fig. 1. It consists essentially of two colorless photometric wedges (i.e., photographic filters with precise gradients in density) which may be rotated simultaneously in front of the eyes of the subject while the latter is viewing an object or performing a visual task. These gradient filters not only reduce the apparent brightness of the visual field due to absorption, but also lower the contrast between the object of regard and its background due to the slightly diffusing character ("*Q*"-factor in photography) of the photographic filters. The diffusing property of the gradient filters is most important and adds greatly to the range in visibility which is encompassable with filters which vary over a given range in transmission. Since the construction, calibration and operation of this instrument have been described in detail elsewhere,[5] only the salient characteristics of this instrument are presented in this discussion.

Scale of Relative Visibility, RV.—This scale is based essentially upon the assumption of a series of test-objects of similar form but varying in size from the smallest visible to infinity which are viewed under certain specified conditions. The series of standard test-objects used for calibrating the Visibility Meter is illustrated in Fig. 2, with some obvious omissions. These objects vary in size from 1 minute to 20 minutes and, in the actual calibration of the visibility meter, were viewed binocularly from a fixed distance.

The Unit of Relative Visibility.—The unit of relative visibility is defined by the resolving power of the normal eye under the arbitrary brightness-level of 10 millilamberts. Actually, it corresponds to the unit of visual acuity which has long been

FIG. 1.

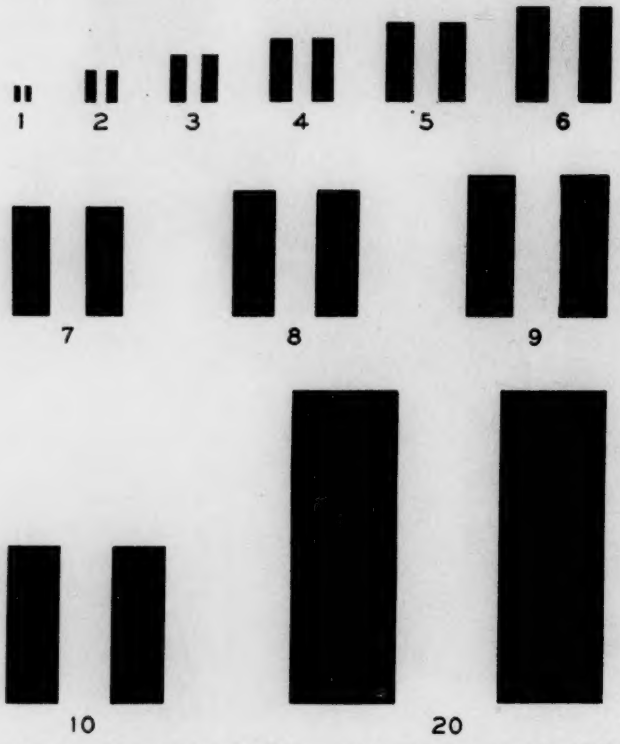


The Laboratory Model of the Luckiesh-Moss Visibility-Meter. This instrument combines the Visibility Meter proper with auxiliary apparatus designed to facilitate the use of the meter.

used as a standard in visual science. Thus a value of "1" on the relative visibility scale indicates that a black parallel-bar object upon a white background, whose critical details subtend a visual angle of one minute, is of threshold visibility when viewed under specified conditions through a region of the

filters of the visibility meter corresponding to a scale value of "1." Hence any object which is barely visible through this region of the filters is assigned a value of unity in relative visibility. In other words, the visibility of such an object, under the conditions of measurement, is equivalent in visibility

FIG. 2.



Reproductions of the parallel-bar test-objects used in calibrating the L-M Visibility Meter and in determining the fundamental relationship between size and contrast as variables of the threshold stimulus. If these objects are viewed from a distance of 8 feet, the numerical values below the test-objects correspond to the visual angles in minutes subtended by the width of the bars or of the space separation between the bars.

to that of the 1-minute standard test-object as viewed by an observer possessing normal vision under a brightness-level of 10 millilamberts. Similarly, a scale value of "2" indicates that the threshold visibility of the object of regard is equivalent to that of a 2-minute standard test-object, etc. These data are strictly rational from the fundamental viewpoint of

visual function. Furthermore, size is a characteristic of our standard test-objects which is readily visualized.

A measure of the reliability of the calibration of our standard or master visibility meter is indicated by the fact that the probable errors of the data which determine the various cardinal points on the relative visibility scale are of the order of one per cent. These data were obtained from a sufficiently large group of subjects possessing so-called normal vision. Also, the fact that children, even pupils in sight-saving classes, use this device proficiently without special training, adds additional proof of its practicability.

Significance of Relative Visibility Data.—Measurements of relative visibility essentially provide a "common denominator" for expressing the visibilities of various dissimilar objects. This basis is the size of the standard parallel-bar test-object of equivalent visibility. In general, the usefulness of this particular scale is due largely to the obviousness of the factor of size in seeing. For example, it is probable that the patient of the eyesight specialist better understands the need for glasses when told that he can barely read letters which are twice as large as those discernible with normal vision than that he can barely recognize letters of 100-per cent. contrast when he should be able to recognize with normal vision the same letters having a contrast of 20 per cent. Obviously, the universal use of the variable of threshold size as a basis for appraising visual efficiency in ophthalmology adds to the significance of such a variable and facilitates its acceptance.

In addition to providing a means by which the visibility of any object may be expressed as equivalent to some one of a series of standard objects of elementary design, this procedure facilitated the correlation of the data obtained with the visibility meter with that obtained in numerous extensive laboratory researches. For example, the standard parallel-bar test-object has been used not only in calibrating the meter but also in our researches involving the four fundamental variables of the visual threshold [5] which have been conducted during the past quarter of a century. In fact, it is through these correlations that we were able to convert the scale of relative visibility into a rational percentage scale of visibility in terms of maximal visibility.

III. VISIBILITY AND VISUAL EFFICIENCY.

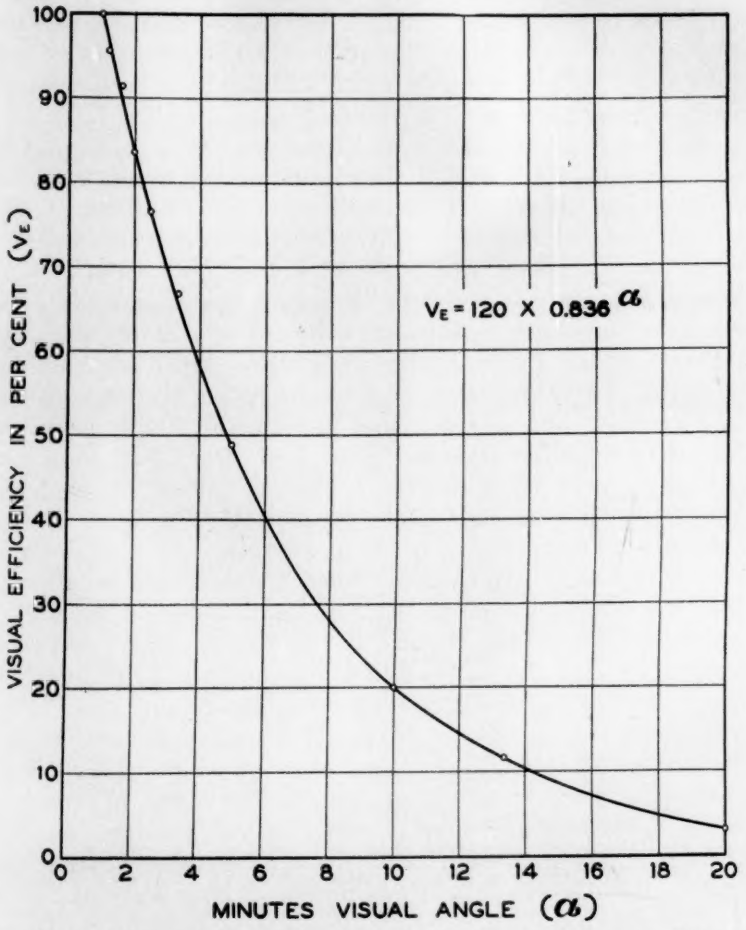
In general, it is well-known that the effectiveness of size, as an aid to seeing, follows a law of diminishing returns. This is also true for other variables in seeing as, for example, the factor of illumination. Thus we proposed some years ago a "footcandle scale of effectiveness" which related this variable with its effectiveness as an aid to seeing. With respect to the factor of size, the characteristic of diminishing effectiveness is also clearly recognized in ophthalmology and other fields of the science of vision. For example, in 1925 the Ophthalmological Section of the American Medical Association adopted the relationship between visual acuity and visual efficiency[6] shown in Fig. 3. This relationship was derived from experimental procedures and from the experiences of the ophthalmologist in appraising the handicap imposed by visual deficiencies. At present, this relationship is widely used for awarding compensation for loss of vision due to eye injuries sustained in industry. It will be noted that "visual efficiency" is not directly proportional to the visual acuity (reciprocals of the threshold size) ratings. For example, an increase in the size of the threshold object from 1 minute to 2 minutes (or a decrease in visual acuity from a Snellen rating 6/6 to 6/12) is correlated with a decrease in visual efficiency from the normal value of 100 per cent. to 84 per cent. Thus visual defects which necessitate an increase in the size of the threshold object by a factor of two are considered to lower visual efficiency only 16 per cent. rather than 50 per cent. as would be indicated by a consideration of size.

Since the L–M Visibility Meter is calibrated in terms of the size of the threshold stimulus, expressed in minutes visual angle, it follows that the data obtaining from the scale of relative visibility may also be expressed in terms of visual efficiency by reference to Fig. 3. For example, a standard test-object which subtends a visual angle of two minutes (or any other object of equivalent visibility) will be of threshold visibility under the following conditions: (1) when it is observed by a person with a visual efficiency rating of 84 per cent. (6/12 in visual acuity); or (2) when it is observed by a person

[6] "Report of Committee on Compensations for Eye Injuries," Section on Ophthalmology, A. M. A., 1925, 368–377.

with normal vision (6/6) through the portion of the gradient filter of the visibility meter corresponding to a scale value of "2" in relative visibility. In both cases, the loss in visual

FIG. 3.



The relationship between the size of the threshold stimulus and visual efficiency as adopted by the American Medical Association.

efficiency is 16 per cent. However, in the one case, this loss is due to subnormal vision; while in the other, it is due to the interposed filter. Furthermore, it is obvious that an object

of threshold visibility when viewed through a given filter would constitute an object of supra-threshold visibility without the filter. Since it has been shown that the influence of the filter is equivalent to a definite loss in visual efficiency, a means is available for appraising the degree of supra-threshold visibility of a given object in terms of the loss in vision that could be sustained before it became invisible. Such comparisons are often quite helpful in appreciating the significance of a given degree of supra-threshold visibility.

Scale of Per Cent. Maximal Visibility, PMV.—Thus far it has been shown (1) that the visibility of any object may be stated as equivalent to a standard object of definite size; and (2) that the visibility of the latter may be expressed in terms of the loss in vision which would reduce its visibility to a threshold value. It will now be shown that a scale of visibility, similar in principle to the scale of visual efficiency, may be developed in which the degree of supra-threshold visibility (or visibility) is expressed in terms of a physical change in the object rather than in the visual mechanism of the observer. The latter scale has been designated as "Per Cent. Maximal Visibility" and abbreviated as PMV. The PMV scale is correlated with the RV scale through the medium of the fundamental relationship between contrast and size as variables of the visual threshold. Such a correlation is possible since the same test-object (parallel-bar) was observed under the same objective brightness and from the same fixational-distance in both the calibration of the meter and the determination of the relationship between contrast and size. The primary advantage of calibrating our visibility meter in terms of contrast (PMV scale) rather than in terms of size (RV scale) is due to the fact that the possible range in contrast varies between finite limits. Obviously, the range in size varies from the smallest visible to a size indefinitely large. A detailed discussion of the development of both scales is available elsewhere.[7]

The two cardinal points on the PMV scale (0 and 100 per cent.) are describable in terms of the physical characteristics of two parallel-bar test-objects which are assumed as stand-

[7] "Thresholds and Supra-thresholds in Seeing," Matthew Luckiesh and Frank K. Moss, *Trans. I. E. S.*, 33, 1938, 786.

ards of maximal and minimal visibility, respectively. The specifications of these arbitrary standards follow:

100 Per Cent. Visibility.—This standard of maximal visibility is obtained with an indefinitely large black object upon a white background (100 per cent. in contrast) illuminated to 10 footcandles when viewed by a person possessing socalled normal vision. In ophthalmology, a person who could not recognize this object would be designated as blind. The degree of supra-threshold visibility of this object is such that it would be of threshold visibility with a contrast value of only 1.3 per cent. It will be noted from Table I that a 20-minute parallel-bar object viewed under a brightness of 10 millilamberts possesses a visibility of 93 per cent. of that of the assumed standard of maximal visibility.

Zero or Threshold Visibility.—This standard of minimal visibility is obtained with a black object, whose critical details subtend a visual angle of 1 minute, upon a white background illuminated to 10 footcandles. In ophthalmology, the recognition of such an object defines the limit of normal human vision. It also represents unity on the scale of Relative Visibility. Obviously, such an object could not be recognized if its contrast-value is less than 100 per cent.

It will be noted that the standards of maximal and minimal visibility are identical with the objects corresponding to the extremes of the scale of Relative Visibility.

Since it is axiomatic that visibility measurements are possible only under threshold conditions, it follows that the degree of supra-threshold visibility of any standard test-object may be determined as a function of the contrast required to produce threshold visibility. For example, it has been shown that 12-point type (Bodoni) is equivalent in visibility to a standard test-object whose critical details subtend a visual angle of 5.66 minutes.[8] Obviously, the latter is an object of supra-threshold visibility. However, it becomes an object of threshold visibility when its contrast is reduced from 100 to 3 per cent. This datum is derived from the threshold relationship between size and contrast for our parallel-bar test-objects illuminated to 10 millilamberts. Similarly, the threshold contrast may be determined for any one of the series of standard parallel-bar test-objects and thus for any object of equivalent visibility. In general, the appraisal of visibility upon a basis of threshold contrast is particularly justifiable

[8] "The Quantitative Relationship Between Visibility and Type-Size," Matthew Luckiesh and Frank K. Moss, JOUR. FRANK. INST., **227**, 1939, 87.

since the perception of contrast is a primary visual function of generally more importance in seeing than the factor of size. For objects of minimal and maximal visibility these values are 100 per cent. and 1.3 per cent., respectively. Between these limits, the PMV scale can be subdivided for convenience into 100 equal logarithmic steps of threshold contrast in accordance with the well-known logarithmic relationship between contrast and visibility. However, since large changes in contrast must be made in order to compensate for the effects of aberrations of the human eye, and since these anomalies are of insignificant importance in the case of all but the smallest of objects, a division of the scale of contrast between the limits of 100 per cent. contrast and 1.3 per cent. would involve some distortion. In other words, certain factors which are of little or no importance in most practical situations would be given considerable weight in the calibration of the PMV scale. It has been shown [7] that the distortion which would be introduced by aberrations may be eliminated by adopting a percentage scale between the limits of 13.0 and 1.3 per cent. contrast.

It is obvious that each value of relative visibility (RV) on the scale of the L–M Visibility Meter corresponds to a definite value on the PMV scale. Thus the visibility meter can be calibrated directly in terms of Per Cent. Maximal Visibility. At present, the transfer from the RV scale to the PMV scale may be made by reference to Table I.

The advantages of the PMV scale are: (1) the numerical values of visibility are weighted in accordance with the visual effectiveness of size as a variable in seeing, and (2) all measurements of visibility lie between 0 and 100 rather than between 1 and infinity as is the case with the RV scale. These advantages of the PMV scale, as well as its rationality, may be indicated by considering an example of its application.

The relationship between visibility (PMV scale) and illumination for 8-point Bodoni Book Monotype is shown in Fig. 4. These data are purposely plotted as arithmetic coordinates in order to facilitate the interpretation of the data by those unfamiliar with logarithmic relationships. Actually, the resultant curve is more complicated than the corresponding logarithmic one as will be noted by comparing it with that shown in the insert. However, logarithmic coordinates are

TABLE I.

The Relationship Between the Scales of Relative Visibility (RV) and Per Cent. Maximal Visibility (PMV).

The RV values correspond to the actual scale division of the L–M Visibility Meter.

RV	PMV	RV	PMV	RV	PMV
1.9	0	4.0	48.6	7.5	72.0
2.0	4.6	4.2	51.0	8.0	73.6
2.1	8.5	4.4	53.0	8.5	75.2
2.2	12.3	4.6	54.9	9.0	76.8
2.3	15.5	4.8	56.7	9.5	78.2
2.4	18.5	5.0	58.5	10	79.6
2.5	21.6	5.2	59.9	11	81.7
2.6	24.5	5.4	61.3	12	83.8
2.7	26.9	5.6	62.7	13	85.4
2.8	28.8	5.8	64.0	14	86.8
2.9	31.1	6.0	64.9	15	88.1
3.0	33.2	6.2	65.9	16	89.4
3.2	37.0	6.4	67.0	17	90.4
3.4	40.2	6.6	67.9	18	91.5
3.6	43.3	6.8	68.9	19	92.4
3.8	46.3	7.0	69.7	20	93.2

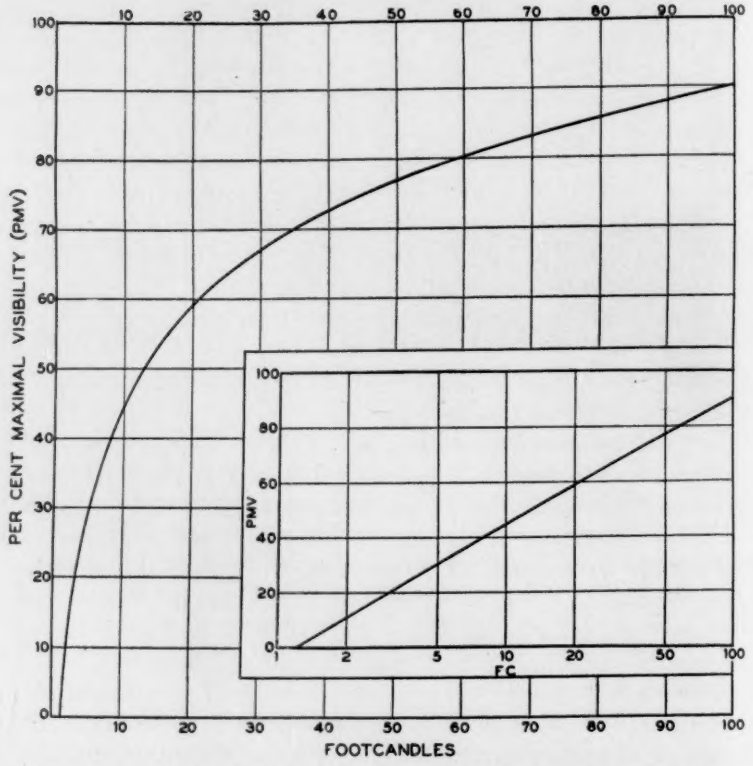
generally used in physiologic optics as well as in other sciences dealing with sensory processes.

It will be noted from Fig. 4 that the lower limit of the PMV scale corresponds to the visibility of 8-point type illuminated to 1.2 footcandles. This is equivalent to assuming that a level of illumination of about 1 footcandle is an appropriate and conservative basis for evaluating the quantitative significance of higher levels of illumination for this particular task. In other words, it is assumed that this basis does not overemphasize the importance of higher levels of illumination. If a more difficult task is considered, such as reading 6-point type, it is obvious that the arbitrary "zero" of the PMV scale would be obtained under a higher level of lllumination.

The data of Fig. 4 show that about 90 per cent. of our standard of maximal visibility is obtained when the illumination on the 8-point type is 100 footcandles. This conclusion is based upon the assumption of socalled normal vision in obtaining these data. Obviously a person with less than normal vision would obtain a smaller percentage of maximal visibility under similar conditions. Thus it appears from these data that 8-point type can be brought to a high degree of

visibility through the utilization of common levels of daylight illumination and levels of artificial illumination which are practically and economically obtainable. However, type of this size is often read under 5 footcandles or less. If 5 footcandles is assumed as an example, it will be noted that less than

FIG. 4.



The per cent. of maximal visibility (PMV) obtained with well-printed 8-point Bodoni Book Monotype under various levels of illumination. The insert shows the same relationship with the footcandle values plotted logarithmically.

30 per cent. of the possible maximal visibility is obtained under this level of illumination.

The insert of Fig. 4 shows the relationship between PMV and illumination when the latter values are plotted logarithmically. It will be noted that the resultant plot closely ap-

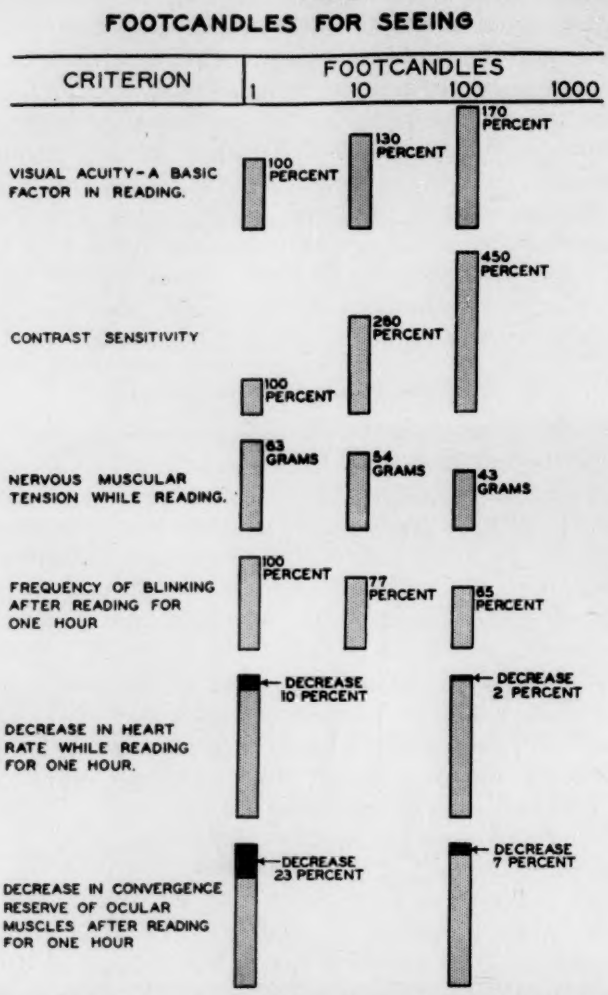
proximates a straight line. This fact indicates the rationality of dividing the PMV scale into equal logarithmic intervals with respect to threshold contrast. In general, visual laws are approximately logarithmic in form so that arithmetic increments in response or behavior are determined by geometric increments in the stimulus. Therefore the logarithmic relationship shown in Fig. 4 is also an indication of the reliability of the data involved in this plot. The latter include two sets of measurements: (1) the determination of the visibility of the 8-point type with the visibility meter; and (2) the determination of the relationship between size and contrast as complementary factors of the threshold stimulus.

IV. VISIBILITY AND EASE OF SEEING.

Since the present discussion is concerned largely with visibility and its measurement, the significance which is attached to such data is a matter of considerable importance. In general, the results obtained in many diversified researches indicate that *visibility* and *ease of seeing* are closely related. As an example, the influence of illumination upon these two considerations is indicated by the experimental data summarized in Fig. 5. It will be noted that both visual acuity and contrast sensitivity are increased as the illumination is increased from 1 to 100 footcandles. These visual functions represent important attributes of the visual mechanism. Furthermore, the data pertaining to certain psychophysiological effects of seeing which we have been able to measure, such as nervous muscular tension, frequency of blinking and extrinsic muscle fatigue, indicate that the task of seeing (reading) becomes easier as the level of illumination is increased. These correlations between visual functions and psychophysiological effects of seeing are typical of those obtained in many researches which have been discussed in detail elsewhere.[5] Thus conditions which provide high degrees of visibility are usually found to be favorable from the viewpoint of easy seeing. This fact obviously augments the significance of measurements of visibility.

The Eyelid Reflex as a Criterion of Ease of Seeing.—Although many of the basic laboratory criteria and procedures are too ponderous and complex in the solution of the practical

FIG. 5.



A summary of results of extensive researches which reveal the influence of illumination upon important aspects of visual efficiency and upon even more important effects of seeing. Researches dealing with these and other effects are revolutionizing the viewpoint from barely seeing to easy seeing.

problems of illumination, they are of the utmost value in establishing and in augmenting the significance of those criteria and procedures which may be used for such purposes. Thus in considering the merit of any proposed criterion in

applied research, it is axiomatic that a useful one must possess (*a*) significance from a fundamental viewpoint, (*b*) adequate sensitivity and (*c*) the characteristic of reasonable applicability in practice. In the course of our researches, we have carefully investigated numerous criteria from these three viewpoints and have developed two of outstanding merit. These are (1) the measurement of visibility by means of the L–M Visibility Meter and (2) the appraisal of ease of seeing as the latter is revealed by the rate of involuntary blinking. In the laboratory, we have successfully applied many other criteria in appraising the influence of physical factors upon both visibility and ease of seeing. However, all but the two criteria mentioned possess some inherent disadvantages from the practical viewpoint.

A consideration of the possible physiological causes of involuntary blinking leads rather directly to the theory that this activity of the eyelids is related to the degree of "tension" or state of "fatigue" of the subject which exists at the time. It has also been observed that the frequency of blinking is remarkably constant for the individual under constant experimental conditions. The latter characteristic suggested the possibility that the frequency of blinking might serve as a practicable criterion of the visual effort expended in seeing under different experimental conditions. Thus it may be possible to determine the relative degree of comfort (ocular, bodily, mental, etc.) afforded by different qualities of lighting while performing a critical visual task such as reading.

In briefly reviewing some of the theories related to the phenomenon of blinking, the terse statement of Duke-Elder [9] is perhaps the most enlightening—"The causation of the movements of blinking has excited little interest. It used to be tacitly accepted that it was a reflex initiated through the fifth nerve to keep the cornea moist and to wash it clear of foreign particles. This, however, is not the case although the movements are increased by peripheral irritation."

It has also been stated by Ponder and Kennedy [10] that "the

[9] "Textbook of Ophthalmology," W. S. Duke-Elder, C. V. Mosley Co., St. Louis, 1934.

[10] "On the Act of Blinking," E. Ponder and W. P. Kennedy, *Quart. Jour. Exper. Physiol.*, **18**, 1927–28, 89.

rate of blinking is closely related to the mental tension of the subject at the time, and that in all probability, the movements constitute a kind of relief mechanism, whereby nervous energy, otherwise unutilized, passes into a highly facilitated path." They further conclude that "all that is necessary to occasion a change in the rate of blinking is a change in the degree of attention of the subject."

In general, we have substantiated these conclusions pertaining to the physiological and psychological significance of blinking and we have greatly extended them by various researches [11] during the past five years. Our results also suggest that an increase in the socalled normal rate of blinking is due, at least in part, to factors associated with fatigue. According to Blount,[12] one of the reasons for blinking is to allow alteration to take place in the tension of the ocular muscles and thus eliminate early fatigue. The investigations of Miles indicate that the movements of blinking are associated with an upward and inward movement of the cornea of 10 to 15 degrees which is accomplished in somewhat less time than is required for the complete lid movement. If the theory of Blount is correct, it follows that the movements of the eyeball on blinking are effective in minimizing the development of muscular fatigue as well as in protecting the cornea from distortion by the tightly fitting tarsal edges of the lids and in serving other important purposes. Thus it appears that attention, effort and fatigue are to be considered as factors which influence the frequency of the periodic movements of blinking.

From the academic viewpoint, an extensive background of knowledge concerning the phenomenon of involuntary blinking has been developed in the fields of physiology and psychology. We have added to this viewpoint a great deal of quantitative data by conducting numerous researches involving a wide variety of visual conditions. The results of ten of these researches are summarized in Fig. 6. An outstanding characteristic of these researches is that the data obtained are in

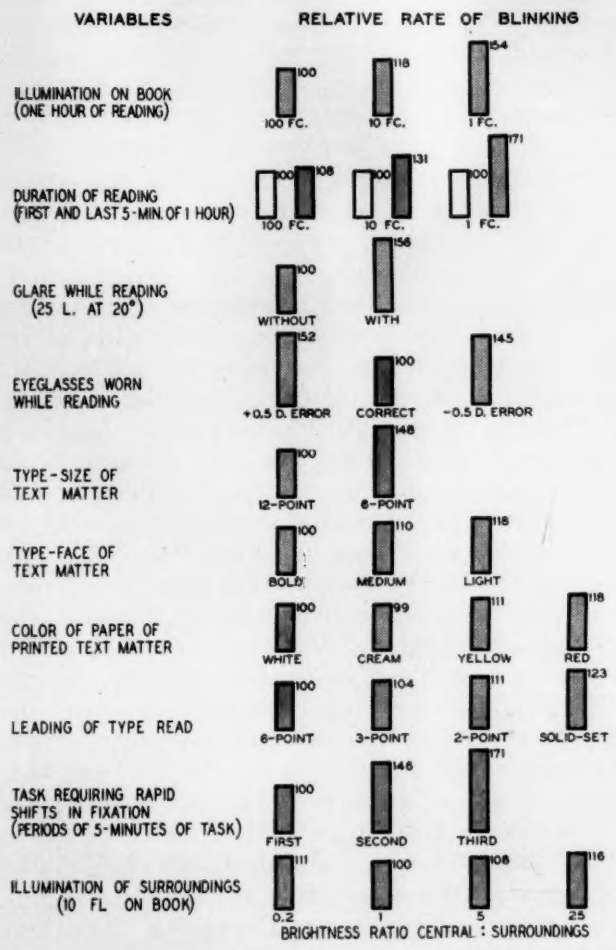
[11] "Frequency of Blinking as a Clinical Criterion of Ease of Seeing," Matthew Luckiesh and Frank K. Moss, *Amer. Jour. Ophthal.*, **22**, 1939, 616.

[12] "Studies on the Movements of the Eyelids of Animals," W. P. Blount, *Quart. Jour. Exper. Physiol.*, **18**, 1927–28, 111.

harmony—thus augmenting the significance and importance of this criterion.

It will be noted from Fig. 6 that an increase in the fre-

FIG. 6.



Changes or differences in the rate of blinking while reading under various visual conditions.

quency of blinking invariably occurs when the conditions for seeing are made more unfavorable in a wide variety of ways. Furthermore, it will be noted that the criterion of involuntary

blinking is one of high sensitivity as is indicated by the fact that rather large differentials were obtained during brief test-periods and under conditions which are commonly encountered in practice. It is also to be emphasized that this criterion may be applied without the distraction of apparatus or the necessity of voluntary acts or responses on the part of the subject. In fact, most of our data was obtained without the subject being aware of the fact that his involuntary blinks were being counted by an observer. In brief, the reflex blink has proved to be an ideal indicator of the influence of not only the obvious factors in the visual situation but also of unobvious and subtle psychophysiological factors.

* * *

Although it is recognized as improbable that a single or master criterion will adequately reveal and appraise all variables in seeing, under all conditions, the techniques associated with the visibility meter and with the recording of the rate of blinking provide great opportunities for placing the specifications of light and lighting on a scientific basis. We have long recognized the importance of visibility and the need for a device with which one could readily measure the visibility of visual objects and tasks in terms of suitable units and scales. It has seemed axiomatic that high comfort or ease of seeing could not be possible without high visibility. However, it seemed possible that the converse might not be generally true. That is, conditions are conceivable under which seeing might be trying, extremely fatiguing or even obviously uncomfortable even though visibility were high. However, a striking feature of the results we have obtained with the rate of blinking as a criterion is that very generally the rate of blinking varies conversely with the visibility of the task such as reading. Therefore, with certain obvious exceptions, a first approximation in the determination of ease of seeing is obtained by means of visibility measurements. In other words, in most cases it appears that visibility measurements not only directly yield important data pertaining to the degree of supra-threshold visibility, but indirectly appraise ease of seeing in many cases and perhaps in most cases.

The foregoing inverse relationship emphasizes more than

ever the need for measuring visibility. It should be borne in mind that the science of vision, including physiologic optics, is based largely upon threshold data or considerations of them. Furthermore, its restricted viewpoint has been extended into the realm of seeing where it has distorted or even concealed the proper considerations of aids to seeing. It is an indisputable fact that in the everyday world of seeing human beings are concerned overwhelmingly with supra-threshold conditions for seeing. Certainly there is no justification for threshold conditions. The efficiency, comfort and welfare of human beings lies in supra-threshold conditions. The science of seeing invades that realm and aims to reveal the efficacy of every controllable aid to seeing in promoting quick, easy and certain seeing. Among the aids to seeing, light and lighting are universally necessary and should be universally available in quantity and quality, respectively, so that seeing is easiest, in the broad sense of the word, compatible with technical possibilities and a true consideration of cost. The latter is possible only by being able to measure the benefits.

New Clue for Oil Explorers.—(*Power Plant Engineering*, Vol. 44, No. 10.) Geophysicists, in searching for oil, believe gamma rays, radiated by the varying rock formations thousands of feet under ground, will provide a tool for finding more than enough oil to meet increasing demands for petroleum products. Oil-well logging by radioactivity, which transmits accurate measurements of these gamma-ray radiations foot by foot down through the well for exact recording on the surface, may open up new vistas of oil discovery. Records of wells that already have been cased with pipe can be taken. This characteristic, it is hoped, will make it possible to find oil formations at other levels in old wells and fields. Extent of such previously-missed formations is unknown, but it is believed that many wells were drilled which completely overlooked valuable formations, or noted them so inaccurately that they could not be found again readily. Radioactivity logging works because every substance is in some degree radioactive. With the development of modern methods of amplifying and measuring these rays, it has become possible to chart variations in ray intensity from rock formations down through a well. Gamma rays, rather than the more familiar alpha and beta rays, are measured because they have short wave-lengths and can penetrate iron pipe. Added to the magnetometer, the torsion balance, the seismograph, the mass spectrograph, the electric log, the core barrel, the aerial camera, and the host of other recently-developed oil-exploration instruments and techniques, well logging by radioactivity is further proof that America's oil men will continue to find oil for years.

R. H. O.

DEPOSITION OF ATMOSPHERIC RADIOACTIVITY ON OBJECTS EXPOSED TO AIR STREAMS.

BY

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ABSTRACT.

When air was blown against various objects, radioactive material was deposited which was identified as the decay products of radon and thoron. The deposition took place on glass, mica, and on the metals copper, brass, steel, aluminum, but not on lead. It was immaterial whether the metals were grounded or insulated. No appreciable electrical potential was produced on the objects by the streaming gas. A deflecting electric field in an ion collector which was inserted in the air-line did not diminish the rate at which the deposit formed. The conclusion followed that the radioactive nuclei were uncharged rather than that they consisted of the types of ions of the atmosphere whose mobilities are known. After snowfall or rainfall the air furnished but a small fraction of the radioactivity observed at other times.

Oxygen gas from cylinders also produced similar deposits on the various objects. Nitrogen, hydrogen, carbon dioxide did not do so. After nitrogen had been directed against aluminum for forty-five minutes, air failed to deposit its radioactive content on the aluminum surface despite a steady stream lasting for almost an hour. Several hours later, however, the deposition became normal. A large discrepancy was found in the intensity of the deposit from two samples of oxygen which had been compressed into their cylinders the same day but tested at different times. The "older" oxygen was much more effective than was anticipated on the bases of the half-life of radon and of the data on radioactive impurities in steel (cylinders).

It is inferred that smoke, dust, etc., blown about in the atmosphere gathers radioactive and hence ionizing substances by the process responsible for the phenomena we have described.

A computation is included on the proportion of radioactive nuclei in the atmosphere which might be expected to be uncharged under equilibrium conditions.

When a strong stream of air was directed against the aluminum window of a Geiger-Müller counter, an increase in counting rate set in whether the window was charged or grounded. The radioactive intensity rose in a gradual manner with time and finally reached a saturation value. When the air stream was stopped the increase in the counting rate did not vanish but its intensity diminished with the characteristic

decay rates of the active deposits of radon and thoron. It was soon discovered that the deposit would gather on all sorts of material in the air stream; glass, mica, copper, brass, steel; and when the objects after having been exposed were placed near the counter, they registered the same kind of radioactive behavior. No activity was detected, however, when the object was of lead. Lead foil and lead turnings, even though the air stream was directed against them a long time, did not increase the counting rate of the tube.

Experiments were carried out to discover whether water and oil which often contaminate the compressed air might be the origin of the activity. All the results were opposed to this assumption. Not only were the trapped water and oil not radioactive but a filter of cotton wadding obviously effective in retaining most of the oil and water produced no alteration in the intensity of the activity deposited. By this time it was held fairly certain that the counter was registering atmospheric radioactivity. The magnitude of the increase in the counting rate varied from day to day. After snowfall or rainfall it was much reduced—sometimes to zero. However the average effect was greater in the winter than in the summer.

Commercial oxygen gas from cylinders also deposited the radioactive substances upon the various materials. The radioactivity from electrolytic oxygen was more intense than the activity from air freshly compressed in this laboratory (when measured under comparable conditions). Two cylinders of electrolytic oxygen filled on the same day were compared in their effects. One of them fifty-nine days later furnished an activity about one third as great as the other had furnished after ten days. The older oxygen was about three thousand times as effective as was anticipated on the basis of the decay period of radon which has a half-life of 3.85 days. This discrepancy was greater than could be accounted for by data on the radioactive impurities in steel,[1] of which the cylinders are composed. Oxygen two weeks old which had been prepared by the distillation of liquid air furnished a

[1] The radium concentration in steel is given as about 1×10^{-14} gms. radium per gm. steel (G. Hoffman, *Ann. d. Phys.*, **82**, 413 (1927)). To account for the extraordinary activity of the older gases from this source would require that the gas be enriched by the diffusion of radon from a layer of steel 2 mm. thick.

deposit about 70 per cent. as active as electrolytic oxygen ten days old. In Fig. 1 may be observed the decay rates of the deposits from oxygen of the different origins. The deposit from the stream of liquid-air oxygen contains considerable activity which we have identified with the active deposit of thoron because of the convex character of the curve. This activity is lacking in the deposit from electrolytic oxygen. However hydrogen gas thirteen days old, carbon dioxide, and nitrogen seven days old, and another sample of nitrogen twelve days old deposited none of the active deposits on the aluminum window of the counter.

An unexpected phenomenon occurred after nitrogen from a cylinder had passed over the counter for forty-five minutes without having affected the counting rate at its basic value. About an hour after the streaming with nitrogen had ended compressed air was sent over the counter in the usual way for about fifty minutes. During all this time the original counting rate continued without appreciable change. At the end of another hour oxygen from a partially filled tank was sent against the window of the counter for eleven minutes, and still no definite increase set in. However, when compressed air was again turned on, the rate accelerated up to about double the basic count.

Gas.	Streaming.		Counts per Minute Average at		Net Effect.
	Begun.	Ended.	Beginning.	Through Run.	
Water pumped nitrogen..	1:47	2:32	8.4±0.4	9.1±0.5	0.7±0.9
Compressed air.....	3:55	4:45			No appreciable
Oxygen from cylinder....	6:04	6:15	9.1±0.5	10.2±1.1	1.1±1.6
Compressed air.....	6:15	6:40	9.1±0.5	19.4±1.4	10±2
Two months later.					
Water pumped nitrogen..	1:42	2:20	9.4±0.6	10.5±0.3	1.1±0.9

The change brought about in the surface of the aluminum by the nitrogen gas, reducing its capacity for retaining the active deposits, was naturally linked to electrokinetic processes and suggested that the deposition was of this nature.

Milhoud [2] had shown that steam would generate a potential of several thousand volts on passing through a tube of bakelite but when the steam was super-heated the effect disappeared. It has been known for a long time that gases free of droplets produce scarcely measurable potentials although Schirmann [3] has reported that sudden opening of a highly insulated cylinder of dry nitrogen charged an electrometer to several hundred volts. In our experiments, the voltage on the case of the counter was not measurably changed by the gas stream nor did an electrostatic voltmeter sensitive to a change in ten volts record any deflection while the air was depositing its radioactivity on a piece of metal. Cotton wadding packed in the air line (darkened with oil, dust etc. where the air entered but clean where it left) did not essentially influence the counting rate. Steel wool charged negatively by 300 volts was not found superior in gathering radioactive deposits to grounded or insulated metal. Perhaps it should be recalled that the classical method of Elster and Geitel [4] for gathering the radioactive content of the atmosphere consists in charging a rather long wire to a negative potential of several thousand volts. However, it has been found [5] that the smoke-laden atmosphere of Cincinnati deposited an activity on an uncharged wire up to 30 per cent. of the maximum intensity obtained with a charged wire. The smoke in its motion in air currents presumably gathers the active deposits in the same way as the objects placed in our gas streams.

To determine whether the radioactive deposits came from charged or uncharged particles in the streaming gases, we inserted an ion collector in the path of the gases and then directed them onto the objects as in the previous experiments. The ion collector consisted of a co-axial cylindrical condenser 140 cm. long. The outside cylinder had a diameter 7.8 cm. and that of the inside cylinder 5.6 cm. Voltages up to 5000 volts were applied from a voltage doubling circuit. The maximum voltage was sufficient to collect all ions having mobilities

[2] M. A. Milhoud, C. R., 198, 1586 (1934).

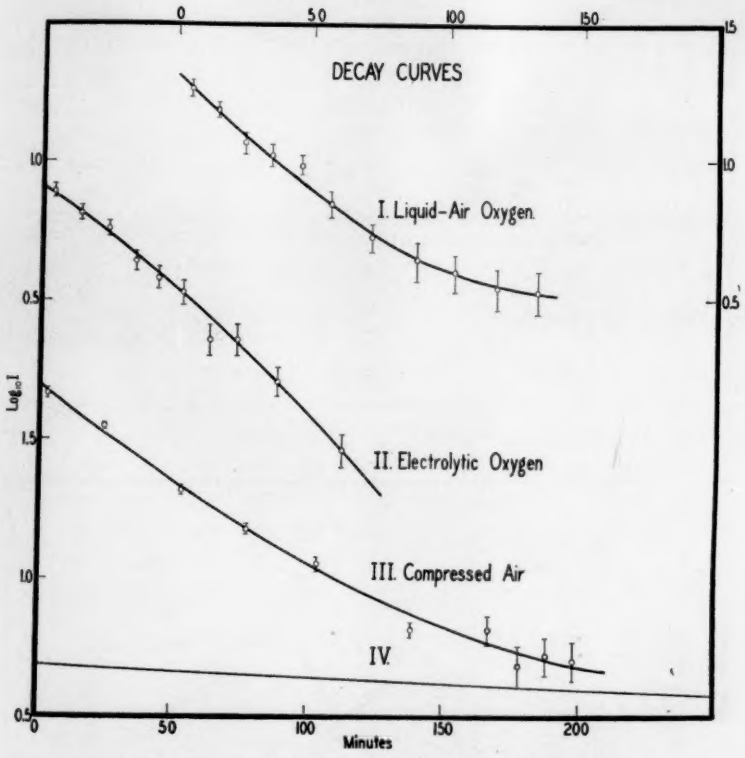
[3] M. A. Schirmann, *Z. Physik*, **46**, 209 (1928).

[4] St. Meyer and E. Schweidler, "Radioakitivität," Teubner, Berlin, 1927, p. 575.

[5] S. J. Allen, *Phys. Rev.*, **26**, 483 (1908).

greater than 0.00034 cm./volt sec. from the gas streaming at 3.5 cu. ft. (atmospheric pressure) per minute. Ions having mobilities of roughly 1.5, 0.07 and 0.0005 cm./volt sec. are known to exist in the atmosphere. By observing the radioactive material deposited with different voltages applied to the

FIG. 1.



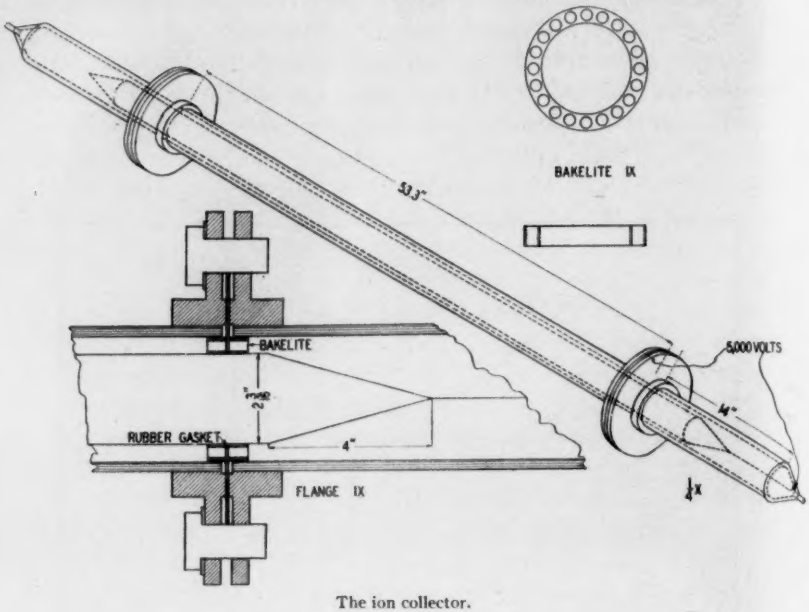
Decay curves of radioactive deposits from streaming gases.

IV The contribution of Th B component in air of III.

ion collector it would be possible to determine the distribution of the radioactive material among the various types of ions.

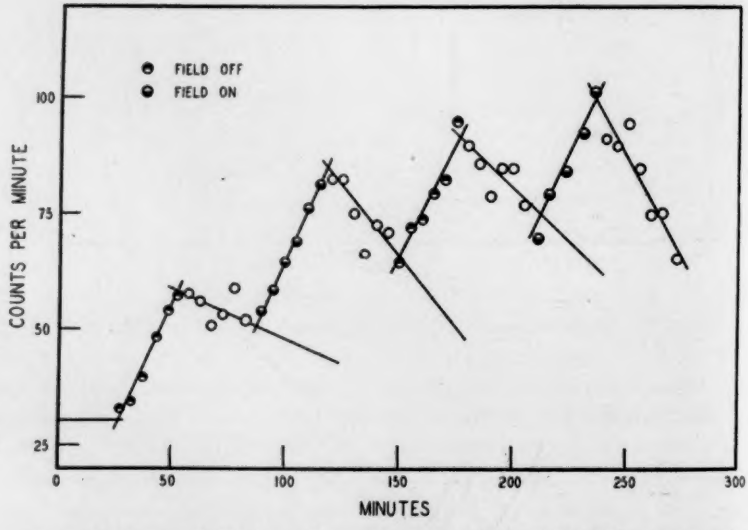
In our first experiments the air entered and also left the condenser at right angles to its length. The ratio of the radioactivity produced on the object when the maximum field was on compared with the activity when the field was off was

FIG. 2.



The ion collector.

FIG. 3.



A steady stream of air blowing against an aluminum wall of a Geiger-Müller counter, after having passed through the ion collector. The effect of the field on the intensity of the resulting deposit is determined by comparison between vertical intervals field-on and field-off. The intervals are to be taken between the corresponding maxima and where the vertical line there intersects the extrapolated decay curve. These were registered when no air was flowing and are indicated by the clear circles. No appreciable difference is to be noted. The equality of the rising slopes is a further confirmation.

$0.89 \pm .13$. However it was known that turbulence in the gas stream would reduce considerably the effectiveness of the collecting field [6] and therefore the cylindrical condenser was modified as represented in Fig. 2 to avoid undue turbulence. Now the ratio of the radioactivity with field on to that with field off was $1.09 \pm .13$. A series of runs furnished data shown in Fig. 3.

The radioactivity is then to be ascribed to neutral radioactive nuclei (or to new type ions of excessively low mobility) rather than to the types recognized as present in the atmosphere. We therefore examine what the relative concentration of uncharged radioactive condensation nuclei may be in the atmosphere under equilibrium conditions (in Chicago).

ESTIMATION OF THE CONCENTRATION OF UNCHARGED RADIOACTIVE CONDENSATION NUCLEI IN THE ATMOSPHERE.

For each of the radioactive elements: RaA, RaB, RaC, ThA, ThB, ThC, and ThC″; the following analysis was carried out.

The assumption was made that immediately after the formation of a radioactive element from its parent the element existed as small positive ions. It was also assumed that the radioactive series were in equilibrium, making the rate of production of small positive ions the same for each member of a radioactive series (except for ThC″, due to branching in the thorium series).

These small positive ions are removed by combination with:

(*a*) small negative ions to form small uncharged radioactive particles,
(*b*) large negative ions to form large uncharged radioactive particles,
(*c*) uncharged condensation nuclei to form large positive radioactive ions.

When equilibrium is established the rate of formation of each type of radioactive particle (small positive ions, large positive and negative ions, etc.) is equal to the rate of removal of that type of particle by combination. Expressing this equality the following relationships are obtained:

[6] G. R. Wait and O. W. Torreson, *Terr. Mag.*, **40**, 425 (1935).

$$\frac{da_+}{dt} = q - \lambda a_+ - \alpha n a_+ - \eta_1 N a_+ - \eta_0 N_0 a_+ = 0,$$

$$\frac{da_-}{dt} = 0,$$

$$\frac{da_0}{dt} = \alpha n a_+ - \lambda a_0 = 0,$$

$$\frac{dA_+}{dt} = \eta_0 N_0 a_+ + \eta_0 n A_0 - \lambda A_+ - \eta_1 n A_+ = 0,$$

$$\frac{dA_-}{dt} = \eta_0 n A_0 - \lambda A_- - \eta_1 n A_- = 0,$$

$$\frac{dA_0}{dt} = \eta_1 N a_+ + \eta_1 n A_+ + \eta_1 n A_- - \lambda A_0 - 2\eta_0 n A_0 = 0.$$

a_+—equilibrium concentration of small positive radioactive ions,

a_-—equilibrium concentration of small negative radioactive ions,

a_0—equilibrium concentration of small uncharged radioactive particles,

A_+—equilibrium concentration of large positive radioactive ions,

A_-—equilibrium concentration of large negative radioactive ions,

A_0—equilibrium concentration of uncharged radioactive condensation nuclei,

q—rate of production of small positive radioactive ions of a given radioactive element,

λ—decay constant of that radioactive element,

α—recombination coefficient for small ions,

η_1—combination coefficient between small and oppositely charged large ions,

η_0—combination coefficient between small ions of either sign and uncharged condensation nuclei,

n—concentration of small ions of either sign in the atmosphere (it is assumed that $n_+ = \eta_1 = n$),

N—concentration of large ions of either sign in the atmosphere (it is assumed that $N_+ = N_- = N$),

N_0—concentration of uncharged condensation nuclei in the atmosphere.

In deriving the above expressions it was assumed that the following combinations coefficients are zero: (*a*) between small positive or negative ions and small uncharged particles, (*b*) between large positive or negative ions and small uncharged particles, (*c*) between large uncharged condensation nuclei and small uncharged particles, (*d*) between large positive or negative ions and large uncharged condensation nuclei, (*e*) between large ions of opposite sign. Furthermore, it was assumed that the relationship $\eta_1 N = \eta_0 N_0$ is satisfied (an assumption usually made in calculation of this type).

The expressions for the equilibrium concentrations become:

$$a_+ = \frac{q}{\lambda + \alpha n + 2\eta_1 N}; \qquad a_- = 0; \qquad a_0 = \frac{\alpha n a_+}{\lambda};$$

$$A_0 = \frac{(\lambda + \eta_1 n)(\eta_1 N a_+) + \eta_1^2 N n a_+}{(\lambda + \eta_1 n)(\lambda + 2\eta_0 n) - 2\eta_1\eta_0 n^2};$$

$$A_+ = \frac{\eta_0 N_0 a_+ + \eta_0 n A_0}{\lambda + \eta_1 n}; \qquad A_- = \frac{\eta_0 n A_0}{\lambda + \eta_1 n}.$$

In the evaluation of these expressions for each of the radioactive species the following numerical data were used:

Equilibrium concentration of radon—1.7 atoms/cc.

Ratio of concentration of radon to thoron

$$\frac{Rn}{Tn} = 1 \times 10^4,$$

$$n = 200/\text{cc.},$$

$$\alpha = 1.6 \times 10^{-6}.$$

N, η_1 and η_0 were evaluated following the analysis of Torreson.[7] The total concentration $N_A = N_0 + 2N$ of condensation nuclei/cc. has been taken to be the value 279,000 determined by J. E. Ives as the average value in Chicago during 1931–33 as reported by Landsberg.[8] The numerical values obtained are:

$$N = 9000/\text{cc.},$$

$$\eta_1 = 2.7 \times 10^{-6},$$

$$\eta_0 = 9.5 \times 10^{-8}.$$

[7] O. W. Torreson, *Terr. Mag.*, **44**, 59 (1939).

[8] H. Landsberg, *Ergeb. d. kosmischen Physik*, **3**, 155 (1938).

The results of the calculation are summarized in the table. (See following page.)

Decay curves 6, 7, 8, and 9 were chosen as being the only ones suitable for this comparison since for the others, either the total intensity is too small, or the material has been activated by O_2 (to which the above calculation would not apply), or the material activated was a metal wool for which the absorption of the radiation in the wool could not be evaluated. The results of the comparison are summarized in the following table.

Curve.	Total Observed Counts.	Time of Flow of Air.	Number of Uncharged Cond. Nuclei.	Counts to be Expected.	Ratio.
6	1.15×10^5	170 min.	2.13×10^6	2.78×10^6	0.041
7	2.6×10^4	90 min.	1.12×10^6	1.46×10^6	0.018
8	7.3×10^4	77 min.	9.64×10^5	1.26×10^6	0.058
9	4.5×10^4	55 min.	6.89×10^5	8.95×10^5	0.050
				Average	0.042

Explanatory Notes:

Column 1.—Refers to number of curve. These curves are not reproduced in this communication. Curve 6 is III of fig. 1.

Column 2.—Total observed counts during decay of activated material. These entries include corrections for (1) extrapolation of decay curves to infinite time (for all curves except 7 it was assumed that the decay beyond the experimental points followed the 10.6 hr. period of ThB; for 7 the experimental curve, being essentially a straight line, was extrapolated along this straight line); (2) the deposited radioactive material decaying while the air was still flowing over the collecting surface before the decay measurements were commenced; (3) the solid angle subtended by the source at the counter (it was estimated that 10% of the radiation was detected by the counter).

Column 3.—Gives the length of time that the air was allowed to flow over the collecting surface.

Column 4.—Gives the total number of uncharged radioactive condensation nuclei in the air passed over the collecting surface. This quantity is equal to the product of the time of flow of the air times the rate of flow of the air (1×10^5 cc./min.) times the concentration of such nuclei (0.125/cc.).

Column 5.—Gives the number of counts to be expected if all of the uncharged radioactive condensation nuclei in the air are collected on the surface and if all of the radioactive disintegrations are detected by the counter. These figures have been obtained from those of Col. 4 by correcting for (1) the fact that some of the condensation nuclei collected decay to give other radioactive elements which in turn decay and are recorded by the counter (i.e. RaA → RaB → RaC and ThA → ThB → ThC → ThC″) and (2) for the absorption of some of the radiation

in the counter window. The figures in this column, then, represent the number of counts which would be recorded by the counter if it counted the beta rays from the whole of the source and if all of the uncharged radioactive condensation nuclei in the air were collected on the surface.

Column 6.—This is the ratio of the entries in col. 2 to the corresponding entries of col. 5 and represents the fraction of the radioactive condensation nuclei present in the air which have been collected on the surface. The average of these values for the four sources is about 4%.

Radioactive Element.	q cc.$^{-1}$ sec.$^{-1}$	λ sec.$^{-1}$	a_+ cc.$^{-1}$	a_0 cc.$^{-1}$	A_+ cc.$^{-1}$	A_- cc.$^{-1}$	A_0 cc.$^{-1}$
RaA	3.5×10^{-6}	3.78×10^{-3}	6.8×10^{-6}	5.7×10^{-6}	3.8×10^{-4}	2.1×10^{-6}	4.8×10^{-4}
RaB	"	4.31×10^{-4}	7.2×10^{-5}	5.4×10^{-5}	1.9×10^{-3}	1.2×10^{-4}	6.1×10^{-3}
RaC	"	5.86×10^{-4}	7.2×10^{-5}	3.9×10^{-5}	1.6×10^{-3}	7.2×10^{-5}	4.3×10^{-3}
ThA	2.1×10^{-6}	4.05	4.2×10^{-7}	2.7×10^{-11}	2.1×10^{-9}	7.9×10^{-15}	2.1×10^{-9}
ThB	"	1.82×10^{-5}	4.3×10^{-5}	7.6×10^{-4}	5.3×10^{-3}	3.5×10^{-3}	1.04×10^{-1}
ThC	"	1.90×10^{-4}	4.3×10^{-5}	7.2×10^{-5}	1.7×10^{-3}	2.4×10^{-4}	9.3×10^{-3}
ThC''	7.6×10^{-7}	3.61×10^{-3}	1.5×10^{-5}	1.3×10^{-6}	8.5×10^{-5}	5.0×10^{-7}	1.1×10^{-4}
Sum.			3.1×10^{-4}	9.3×10^{-4}	1.1×10^{-2}	4.0×10^{-3}	1.24×10^{-1}

Total concentration of radioactive atoms = 0.140,
Total concentration of uncharged radioactive atoms = 0.125,
Total concentration of + charged radioactive atoms = 0.011,
Total concentration of − charged radioactive atoms = 0.004,

$$\text{Ratio of uncharged to total:} = \frac{0.125}{0.140} = 0.89,$$

$$\text{Ratio of charged to total:} = \frac{0.015}{0.140} = 0.11.$$

We estimate, then, that the uncharged radioactive condensation nuclei constitute about 89 per cent. of all the radioactive nuclei in the atmosphere. Actually, the air which entered the collector had already lost a large fraction of its condensation nuclei. Torreson and Wait [9] had observed that even though no electric field was present the walls of their ion collector had removed 8 per cent. of the condensation nuclei. In our experiments, a much larger proportion of the nuclei must have been intercepted since in between the compressor and the condenser the air passed through about 60 ft. of iron pipe two inches in diameter, about 60 ft. one inch in diameter. Besides in the air line there were baffles, bends and a big steel reservoir.

[9] O. W. Torreson and G. R. Wait, *Terr. Mag.*, **39**, 47 (1934).

Synthetic Chemicals From Petroleum.—(*The Oil and Gas Journal*, Vol. 39, No. 27.) L. Rosenstein of the Shell Chemical Co. in a paper presented before the Refining Division at the recent meeting of the American Petroleum Institute stated that the manufacture of synthetic chemicals from petroleum and natural gas has been one of the major developments in the chemical industry during the past decade. As an example, Shell Chemical Co.'s production of ammonia has increased from 4,500 tons in 1931 to 27,000 tons in 1939; of solvents from 90,000 lb. to 57,000,000 in the same period. A continually increasing variety of chemicals of exceptionally high purity is being made available at constantly decreasing cost from cheap raw materials whose supply is stable, abundant, and remarkably adaptable. Alcohols, ketones, and esters made from refinery gases that formerly were used only as furnace fuel now are known quite well to chemical markets. Many new products, now produced on laboratory and pilot-plant scale by Shell Development Co., in due course will join them. Among these are unsaturated alcohols and chlorides, glycerol and its derivatives, and butadiene. The entrance of the petroleum industry into the field of synthetic chemicals has had a profound influence upon the development of synthetic gasolines; thus the development of isooctane was associated closely with that of secondary butyl alcohol. Other similarly close relationships may be expected as petroleum chemicals play an increasingly important part in the economics of the industry.

R. H. O.

RELATIVE EFFICIENCIES OF RADIOACTIVE NEUTRON SOURCES.

BY

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ABSTRACT.

A number of radium-beryllium and radon-beryllium neutron sources are compared. It is found that the radon sources may vary in efficiency by more than a factor of two, while the radium sources seldom vary by more than 15 per cent. These efficiencies are based on the customary assumed ratio of gamma ray activity to neutron-production. Sources manufactured under similar conditions are found to compare more favorably; i.e. with less variation among themselves. The reasons for the variations are investigated, and also the factors influencing the efficiency. It is found that, for the radium sources, the mixing is especially important; the size of the radium grains is important; the purity of the beryllium is important. The geometrical shape of the source and the absolute amount of beryllium are not found to be especially important. For the radon sources, it is in addition especially important that the container be as full as possible, with as little space as possible occupied by gas alone. The contribution of photoneutrons to the total emission is investigated, and found to be of the order of two tenths.

Many of the investigations carried out in the field of nuclear physics during the past few years have required the use of neutron sources. A convenient source of neutrons and one which has been widely used may be prepared by mixing either radon or radium with beryllium. It has been generally assumed that the neutron yield of a radon-beryllium source is proportional to its gamma ray strength, so this type has been used as a standard in measuring the neutron yield from other sources.

Amaldi and Fermi [1] determined the number of neutrons emitted from their sources and found 27,000 neutrons per

[1] Amaldi and Fermi, *Phys. Rev.*, **50**, 898 (1936).

second per millicurie of radon. Bakker[2] later made a similar determination for a Ra-Be source using the same method employed by Amaldi and Fermi. A comparison of the results of these two experiments indicates that the radium source was 78 per cent. as efficient in the production of neutrons as the radon sources. Paneth, Bluckauf, and Loleit[3] made a similar comparison of Ra-Be and Rn-Be sources using a spectroscopic method to determine the helium yield from the reaction $B_5^{10} + N_0^1 = Li_3^7 + He_2^4$. They concluded that the radium source was 75 per cent. as effective in the production of neutrons as was the radon source. Ollano[4] measured the number of neutrons emitted per second per unit of gamma ray strength from two Ra-Be sources which he had prepared. He used the same method that had been used by Amaldi and Fermi, and his results indicated efficiencies of 82 per cent. and 55 per cent. for his two sources when compared to the 27,000 neutrons per millicurie per second found by them. Little information is given concerning the physical details of any of these sources.

Recently, while working with several radium-beryllium sources it was noticed that the neutron yield per unit gamma ray strength was not the same for the different sources. After comparing these sources accurately it was decided to measure their yield in terms of a radon-beryllium source. Two such sources were available. The results of these measurements[5] indicated that the gamma ray strength is not always a reliable measure of neutron emission in the case of either the Ra-Be or the Rn-Be mixtures.

In the hope of throwing more light on the subject of the relative efficiency of such sources a more comprehensive plan for comparing a greater number of sources was undertaken. The experimental procedure was planned in such a manner as to determine the effect of the following factors on the neutron-producing efficiencies of the sources: (1) total amount of beryllium in the source; (2) the geometrical shape of the source; (3) the effect of impure beryllium; (4) the effect of

[2] Bakker, *Physica*, **4**, 723 (1937).
[3] Paneth, Gluckauf, and Loleit, *Proc. Roy. Soc.*, **157**, 412 (1936).
[4] Ollano, *N. Cimento*, **16**, 456 (1939).
[5] Murphy, Bright, Whitaker, Korff, and Clarke, *Phys. Rev.*, **58**, 88 1940).

empty space in the containing bulb; and (5) also the contribution of the photo-emitted neutrons to the total number measured.

PHYSICAL DESCRIPTION OF SOURCES.

Five radium-beryllium and six radon-beryllium neutron sources have been used in making the comparisons described here. The radium sources were not prepared by us and for that reason all of the details of their construction are not known. They were all prepared by the same company but not by the same individuals. Some of the physical details of these sources are given in Table I, while others are described below. All the sources have been numbered and will be referred to by the numbers shown opposite them in the tables. Four of the radon sources were prepared especially for these studies and include features designed to emphasize certain factors affecting the neutron yield. Some of the physical details of these radon sources are given in Table II, and others are discussed below.

The radium sources were prepared by pouring radium sulfate solution over powdered beryllium and stirring thoroughly. The beryllium onto which the radium salt solution had been poured was then carefully dried and packed into the container. The activated beryllium was sufficient to fill the container of sources 1, 3, and 5, but in the case of 2 and 4, additional beryllium was added in order to fill the container. One gram of ordinary beryllium was added to the radium covered beryllium in source number 2, while 5 grams were similarly added to source number 4. The radium covered beryllium making up the first four sources was placed in metal tubes of either brass or steel while the fifth source was in a small spherical bulb made of Gundlach glass of wall thickness 0.5 mm. This glass bulb was then placed in a protective copper container of the same wall thickness.

The radon-beryllium sources were prepared by admitting radon through a capillary into glass bulbs containing powdered beryllium. The bulbs were then sealed off at the capillary. The bulbs were made of Gundlach glass and the smaller ones (6, 7, 8, 9) were sealed into Gundlach glass tubes of about 60 cm. length to facilitate handling.

The sources numbered 6, 7, and 9 were in small tear-drop shaped bulbs into the small end of which was packed aluminum foil to prevent the beryllium powder from falling into the capillary before or during the sealing off process. The other radon sources did not have this foil. After the sources had lost their activity to such an extent that they could be more readily handled they were carefully examined for any features that could effect their efficiency as neutron sources. These observations will be discussed later.

We have no detailed information about the beryllium used in the radium sources. That used in the radon sources was analyzed and found to be quite pure (98 per cent.) except for that used in source number 6 which contained heavily oxidized beryllium (75 per cent. Be by weight).

The radium sources had their radium content certified by the Bureau of Standards while the radon content of each radon source was determined by at least two gamma ray comparisons with standard radium needles. These two comparisons were made several days apart in order to check on possible leakage of the seals. No evidence of any leakage was detected.

DESCRIPTION OF APPARATUS AND EXPERIMENTAL PROCEDURE.

The neutron detecting apparatus used in comparing the relative neutron yields of these sources consisted of a boron trifluoride filled ionization chamber coupled to a suitable amplifier and scaling circuit. The counting rate was determined with and without a 0.5 mm. cadmium filter for each of the geometrical arrangements of source, detector, and paraffin. The difference between these counting rates was taken as a measure of the number of neutrons emitted by the source.

In the first arrangement the various sources were placed successively in a cylinder of paraffin whose dimensions were 15 cm. in diameter and 20 cm. in length. See Fig. 1. A hole of just sufficient size to admit the sources was made through this paraffin along a diameter and about 2 cm. from one end. The sources were suspended in the center of this small cylindrical hole with the middle of the source on the axis of

the paraffin cylinder. The ionization chamber was placed on the axis of the paraffin cylinder, and at such a distance from the source position that the counting rate for the strongest sources was well below the safe rate for the apparatus.

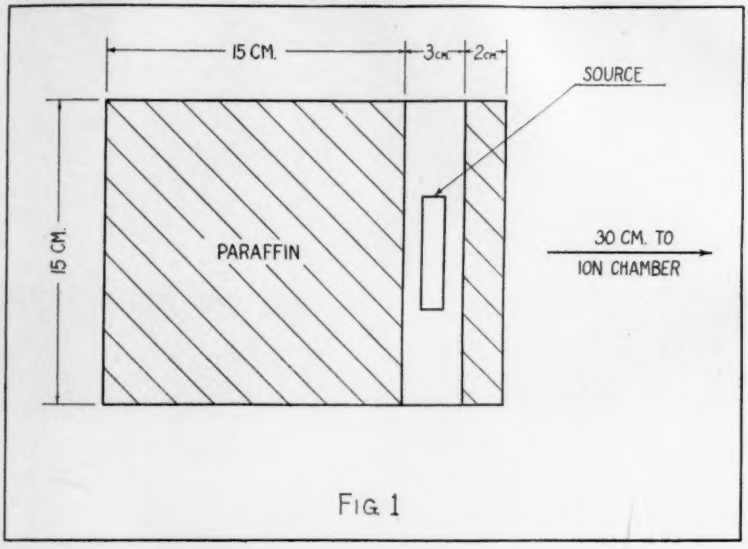


FIG. 1

In the second arrangement shown in Fig. 2 the sources were placed in a horizontal position on the bottom of a cylindrical hole in a large block of paraffin and the BF_3 chamber was placed so as to count the neutrons which diffuse out in a direction parallel to the axis of the cavity. The hole in the paraffin block was 15 cm. in diameter and 15 cm. deep.

In view of the fact that the sources which were to be compared had different dimensions it was advisable to determine to what extent the position of the source in the paraffin block affected the counting rate. This was done by suspending one of the Ra-Be sources in various positions along the axis of the hole in the block of paraffin shown in Fig. 1, and taking the counting rate for each position. No appreciable change was detected when the source was moved a few centimeters in either direction. This fact would seem

amply to justify the use of this arrangement for the comparison of sources of different dimensions.

A precautionary test was made to determine if the ratio of the response rates of the apparatus with the different sources in position is also the ratio of the neutron emission

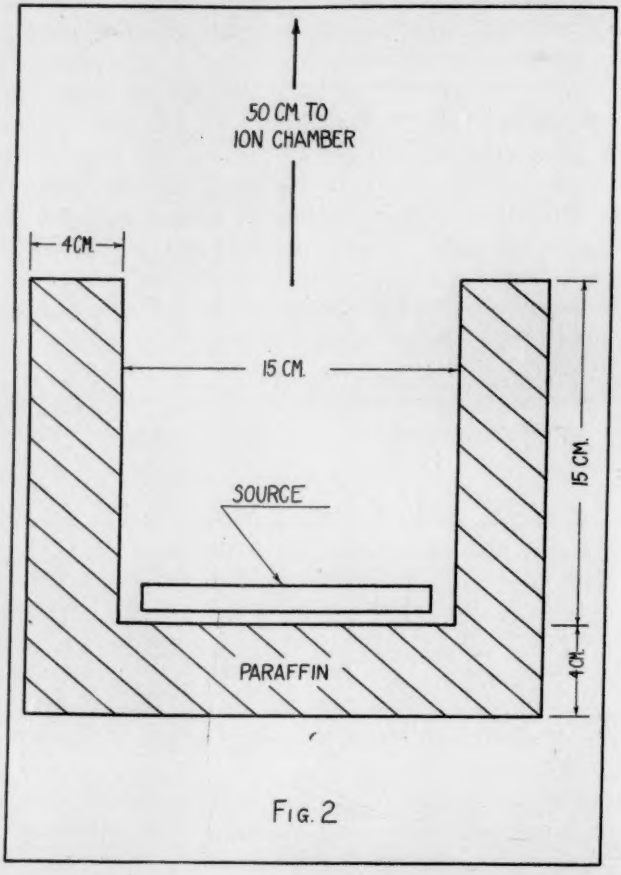


FIG. 2

rates of the two sources. Since the neutron emission has been measured by the difference between the response rate of the apparatus with and without a 0.5 mm. cadmium filter, any response due to gamma rays will not affect the results for any one source. However, it is possible that the efficiency of detection of the neutrons will be changed by the presence

of high intensity gamma rays. If such a change were to take place it would invalidate any comparison of neutron emission by two sources of different gamma ray strength. In order to determine whether the presence of gamma rays affected the counting rate of the apparatus the following test was carried out. A group of radium needles containing a total of 200 mg. of radium was placed in the paraffin block. The presence of these did not alter the background count. A Ra-Be source and the radium needles were placed simultaneously in position. The counting rate was found to be the same as when the Ra-Be source alone was present. This was considered sufficient evidence that gamma rays did not affect the counting rate or the efficiency of the apparatus.

In order to determine whether the radon in the source bulbs was distributed uniformly throughout, two lead blocks about 5 cm. thick were arranged with a slit between them of .5 cm. width as shown in Fig. 5 and located at a convenient distance from the counting apparatus. Source number 11, which was about three quarters full of Beryllium, was used for the following test. The bulb was placed behind the lead shield in such a manner that gamma rays from .5 cm. of its length could reach the counter at one time. Counting rates were taken for several sections of the bulb, including the upper end where there was no beryllium. The results indicated that the radon gas was uniformly distributed in the bulb.

RESULTS.

The comparative neutron producing efficiencies of the radium sources are shown in the last column of Table I.

TABLE I.

Description of Radium-Beryllium Sources.

Source Number.	Diameter of Container.	Quantity of Beryllium, Gm.	Quantity of Radium, Mg.	Neutrons per Mg. (Relative).
1	1.90	5.0 Mixed	211.69	1.00
2	3.14	5.5 Mixed 1.0 Added	200.09	.97
3	1.70	5.5 Mixed	200.14	1.00
4	1.60	4.0 Mixed 5.0 Added	200.62	.85
5	.55	.25 Mixed	9.87	.88

As is shown in the table, three of the sources have almost the same efficiencies while the other two are lower by 12 per cent. and 15 per cent. The efficiencies of the radon sources are shown in the last column of Table II. The numbers here

TABLE II.

Description of Radon-Beryllium Sources.

Source Number.	Quantity of Be, Mg.	Neutrons per Millicurie (Relative).
6	100	.55
7	120	.76
8	1300	1.35
9	120	1.15
10	1500	1.08
11	990	.97

give the relative neutron producing power of the radon sources per unit of gamma ray strength in terms of radium sources 1 and 3. The differences in efficiency among the radon sources is much more marked than is the case with the radium sources.

The most marked deviation from expected efficiency is that found for radon source number 6, where the efficiency is only 55 per cent. of that of the radium sources used as references. This source was of about the same size as sources 7 and 9 but filled with oxidized beryllium.

Source number 7 was originally thought to be almost identical with number 9 but careful examination after the radon had decayed to a small fraction of a millicurie revealed that during the sealing off process a small thin walled spherical bulb of about 3 mm. in diameter was formed at the point where the seal was made. This bulb was joined to the main bulb containing the beryllium by a capillary of about 0.5 mm. diameter.

Sources 8 and 10 were very similar except that examination after decay revealed that there was a globule of mercury weighing 2 grams in source 10 which could only be detected by observing the motion of the beryllium powder when the source was shaken. Source number 10 is about 25 per cent. less efficient than number 8. We attribute this lower effi-

ciency to the mercury and/or to the fact that the less efficient of these sources had a somewhat greater percentage of space that was not filled with beryllium.

A part of the beryllium used in source 8 was removed from it and was used in the construction of number 11, which was made in the form of a long thin cylinder with 75 per cent. of its volume filled with beryllium powder. Its relatively low efficiency seems definitely traceable to the fact that a large fraction of its volume did not contain beryllium.

DISCUSSION OF FACTORS INFLUENCING THE EFFICIENCIES.

While it is not possible to express quantitatively the influence of all the various details of source construction, we believe that it is possible to get some qualitative idea as to the effect of several factors. The most important factors are those which influence the probability that the maximum number of alpha particles shall be able to strike beryllium nuclei. The contributions due to photoneutrons are discussed below.

(*a*) *Geometrical Shape of Source.*—It is found that the geometrical shape of the source is unimportant, as long as no extremes are taken. The surface of the container will generally be small compared to the area of the beryllium particles, and hence the fraction of alpha particles striking the walls will be small. Sources 2 and 5 were the most compact, 3 the most extended.

(*b*) *Amount of Beryllium.*—The neutron producing efficiency was not found to vary rapidly with the amount of beryllium used, over the range from 0.1 to 1.5 grams, used in the radon sources. In the radium sources, the ratio of beryllium to radium was practically constant.

(*c*) *Fullness of Container.*—It is found important, in the case of the radon sources, that the container be as full of beryllium as practicable. Tests are described, which show that the radon is distributed almost uniformly in such tubes as have been used. No evidence is found for the occlusion of important fractions of the radon on the beryllium granules. It is evident that, in the case of source 9, practically no alpha particles formed in the side bulb could collide with beryllium

nuclei. Similarly we may attribute the differences between sources 8 and 11 to the fact that more of container 11 was empty. In the case of small sources, such as 6, 7 and 9, it is difficult to seal the tube off so as to leave a negligible amount of empty space. The total volume being only 0.2 cc., a dead space of as little as 0.02 cc. constitutes an appreciable fraction.

(*d*) *Purity of Beryllium.*—Tests showed that the purity of the beryllium is of considerable importance It is evident that, since the neutron-yield curves increase rapidly with alpha particle energy, an alpha particle which has had to penetrate even a thin oxide layer, will lose enough energy to reduce appreciably its neutron-producing efficiency. Since the oxide layer will be on the surface of the beryllium grain, it may not appear, when analyzed chemically, as a large fraction of the total beryllium which is an oxide. Source 6 was made with oxidized beryllium, and indicates the large reduction in efficiency which can thus occur; the source was otherwise similar to 7 and 9.

(*e*) *Size of Radium Grains; Mixing.*—It is important that the radium grains be small, in order that the alpha particles formed in the interiors thereof will have the largest probability of emerging with undiminished energy. In the preparation of these sources, radium sulfate was used since its crystals are smaller than those of the bromide or chloride. Good mixing is essential, and the ideal conditions are most closely attained when each small beryllium grain is coated with a monomolecular layer of radium.

DIFFERENCES BETWEEN RADIUM AND RADON SOURCES.

In the ideal source, we would expect greater yield from the radium source than from that with radon, since there will be one more alpha particle available. However, it is evident that factor (*e*) will generally reduce the yield by more than this amount.

THE PRODUCTION OF PHOTONEUTRONS.

Since neutrons are produced in the radioactive neutron sources by both the (a, n) and the (γ, n) reactions, and since

it is evident that the efficiencies of the two processes will be influenced in different ways by various factors, it is necessary to determine the relative importance of these two processes. As we have shown above, the factors influencing the efficiency of the (a, n) reaction are those which control the chances that each alpha particle shall strike a beryllium nucleus. The (γ, n) process will be influenced by quite different factors; the gamma rays will not be appreciably absorbed in emerging through lumps of radioactive material, nor in penetrating through oxide layers.

It is evident that N photoneutrons will be produced by a flux of I gamma rays per cm. sq. per second passing through a one cc. column of material of atomic weight w and density ρ as given by:

$$N = IA \frac{\rho}{w} \int \sigma_{(E)} dE, \qquad (1)$$

where σ is the production cross section for neutrons by gamma rays of energy E, and A is Avogadro's number. If we take σ as 2×10^{-28} sq. cm. for average gamma rays from radioactive material, and l as 1 cm. in solid beryllium, then N/I is 2.6×10^{-5} neutrons per gamma ray. It is evident that a large amount of beryllium is necessary in order to make this process an efficient source of neutrons.

It will be recalled that about 3.7×10^{7} alpha particles are emitted per sec. from 1 mg. of radium, and a like number from each of the four alpha emitters in equilibrium with it. Fermi's value of 2.7×10^{4} neutrons per mc. per second indicates that about 1.5×10^{-4} of all alpha particles produce neutrons. If we suppose one gamma ray for each alpha particle, then the total emission of photoneutrons from a Ra-Be mixture of average gamma ray path length 1 cm in solid Be will be about 17 per cent. of the alpha neutrons.

With these considerations in mind, we made the following experimental tests of the photoneutron contributions. A radioactive source was placed inside a beryllium block, in the form of a hollow cylinder, 6 cm. long, 6 cm. OD, 2 cm. ID. The block was placed inside a paraffin block of variable dimensions (see Fig. 3). Counting rates were determined with this arrangement, with and without the Be cylinder,

which could be removed without disturbing the source. With 1 cm. of paraffin and with the beryllium block in place, the number of neutrons was found to be 3.85 times greater than with no Be. We should expect, following Eq. 1, that if the source had $l = 1$ cm. of Be, and we added 2 cm. Be, then the photoneutrons would be greater by a factor of 3.

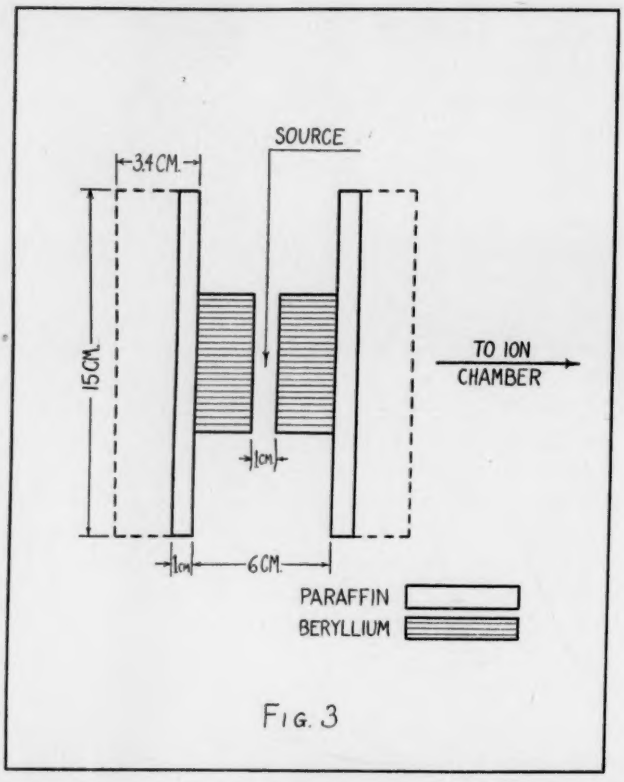


FIG. 3

If the photoneutrons comprised initially 17 per cent. of the total, then with the Be block they would comprise 38 per cent.

The interpretation of this experiment is complicated by the fact that photoneutrons will have, on the average, much lower energies than alpha neutrons. Hence they will be differently affected by the amount of paraffin. This was shown by arrangement *B*, where the thin paraffin cylinder

($B - 1$) emphasized the photoneutrons and did not slow the alpha-neutrons down enough to make detection efficient. In this case an increase of a factor of 3.8 was noted when the Be block was added; but for the thicker paraffin ($B - 2$), the increase factor was only 1.88.

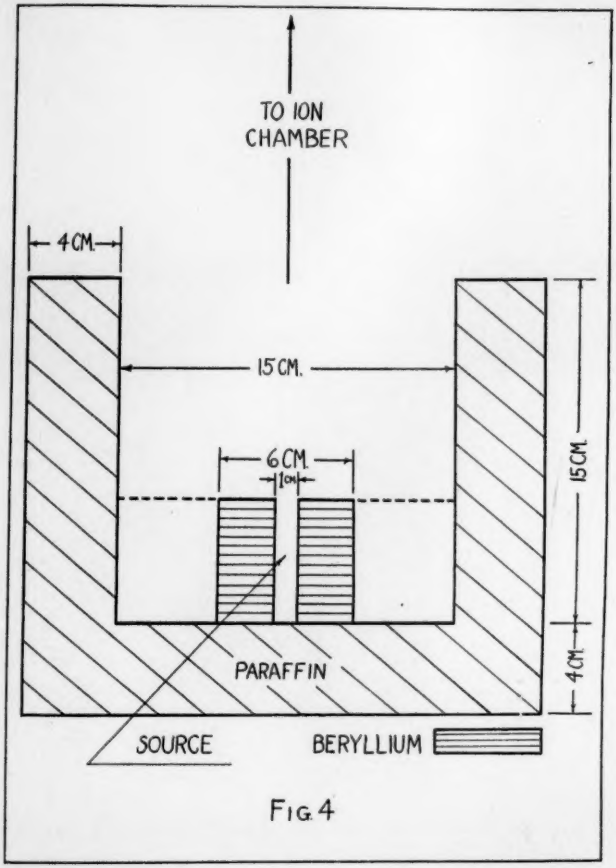


FIG. 4

The conclusions drawn from these experiments on photoneutrons are: (1) that photoneutrons are relatively unimportant in sources of the types customarily used, (2) that quite thick blocks of Be are necessary to increase substantially the yield, and (3) that therefore the amount of Be used in the

average source is not important and may be reduced considerably below that sometimes used. It must be emphasized, however, that the degree of mixing is important, since this determines the probability that each alpha particle may

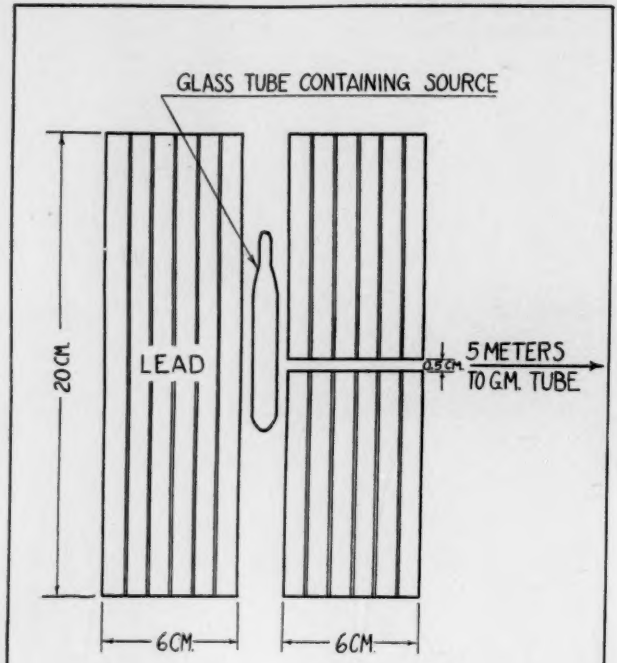


FIG. 5

strike a beryllium nucleus without losing its energy in penetrating intervening matter.

These measurements indicate that a better standard of neutron production than that of neutrons per millicurie per second is needed in order to correlate work done in various laboratories.

ACKNOWLEDGMENTS.

We are happy to acknowledge the great amount of cooperation which we have received in doing this work. Grants from the American Academy of Arts and Science (to M.D.W.) and from the American Philosophical Society (to S.A.K.) have made this work possible. We are much indebted to Mr. C. B. Braestrup of the Physical Laboratory of New York City Department of Hospitals and to Dr. H. T. Clarke of the College of Physicians and Surgeons for their coöperation. The Radium Chemical Company has been very coöperative and has contributed substantially to this work. The American Oncologic Hospital of Philadelphia has very kindly supplied especially prepared radon-beryllium bulbs which were of great value to us.

An Electronic Relay for Initiating Vapor Discharge.—EDWARD C. DENCH. (*Electrical Engineering*, Vol. 59, No. 11.) The recent introduction of low-voltage fluorescent lamps has created a need for automatic control auxiliaries. Several methods have been devised for the automatic starting and operation of these lamps, the most recent being a device known as the "glow relay." Earlier methods had certain disadvantages as to cost, effect on the lamps, circuit efficiency, dependability, and ease of wiring. The invention of the glow relay resulted from attempts to overcome these undesirable features. The relay is essentially a small glow-discharge lamp, comprised of two electrodes in a glass envelope containing neon. The container is about the size of an automobile headlight lamp. One of the electrodes is constructed of a heat-sensitive bimetallic strip with a contact member at its extremity. The other electrode is a projecting wire placed so that it will touch the contact member when the bimetallic strip flexes due to heating. When a gaseous glow discharge takes place in this device, the bimetallic strip is heated by positive-ion bombardment and flexes so that the contacts are closed. When the contacts make an electrical connection, the glow discharge is short-circuited. The device is designed to have a break down voltage of about 90 to 100 volts. The glow relay has many advantages over previous fluorescent-lamp automatic-starting devices. In addition, it may be stated that the relay, although first developed for use with fluorescent lamps, is not limited to use with these particular lamps. It may find application in the automatic control of other discharge devices of the same nature which exhibit the same phenomena.

R. H. O.

AN INSTRUMENT FOR MEASURING SHORT INTERVALS OF TIME.

BY

ERIC A. WALKER,

University of Connecticut.

SYNOPSIS.

This paper describes a meter for measuring short intervals of time. Full scale deflections of 0.001, 0.1, and 1.0 second can be obtained by the use of a selector switch. This meter will indicate the length of time a contact remains closed, or the interval of time between the closing of one circuit and the opening of another. The device has a linear scale for any chosen range. It measures time by the charge which flows to a condenser during the interval. The charge is found by reading the potential difference on the condenser with a sensitive vacuum-tube voltmeter. The theory of the circuit and its advantage over other devices for the same purpose are discussed.

INTRODUCTION.

The purpose of this paper is to describe an electrical circuit for measuring short intervals of time. Such a device can be used for timing relays, circuit breakers, or even for measuring the reaction times of individuals in psychological studies. These intervals are the interval during which a switch or key remains closed, or the interval between the closing of one circuit and the opening of another, or the interval between closing two circuits. Such intervals, between one ten-thousandth and one second, have been measured by this device. Doubtless longer or shorter intervals can be measured by changing the circuit constants.

The reading which indicates the time interval appears on a meter calibrated in fractions of a second and can be kept on the meter for several minutes.

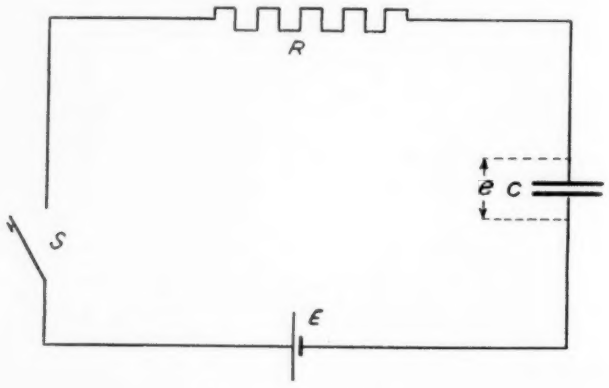
A number of other devices have been developed for the purpose of measuring short intervals of time, but most of them have some rather obvious defects. A stop watch will measure intervals as short as one-tenth of a second, but the personal error of the operator may be several times the time being measured. To measure the interval of time during

which a contact remains closed, one can connect the contact in series with a synchronous clock and an alternating current source. However, the clock will not stop as rapidly as it starts and there will be an error of about one-tenth of a second. Some devices reduce this error by having a counting device connected to and disconnected from a synchronous motor which runs continuously. As the counter itself has but little inertia it will stop rapidly, and the error is reduced considerably. Another type of device records a number of cycles of an alternating voltage on a photographic film. Such a device avoids any error from inertia but the developing of the film takes time and the expense is relatively high. The device to be described has a much smaller error than most of these devices, and has the advantage of being direct reading.

DESCRIPTION.

The method of operation of this meter can be understood from Fig. 1 (*a*). A series circuit with a resistance and

FIG. 1 (*a*).



Transient circuit for timer.

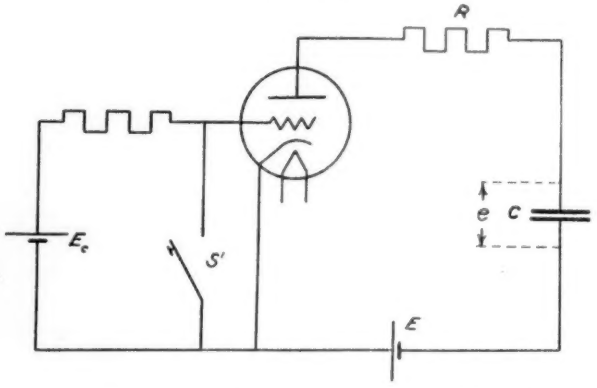
capacitance is connected to a voltage source through a switch *S*. If time is measured from the instant the switch closes, the voltage e, across the condenser, is given by:

$$e = E(1 - e^{-t/RC}). \qquad (1)$$

If the voltage is plotted as a function of time, Fig. 2 is obtained. The initial rate of voltage rise is given by:

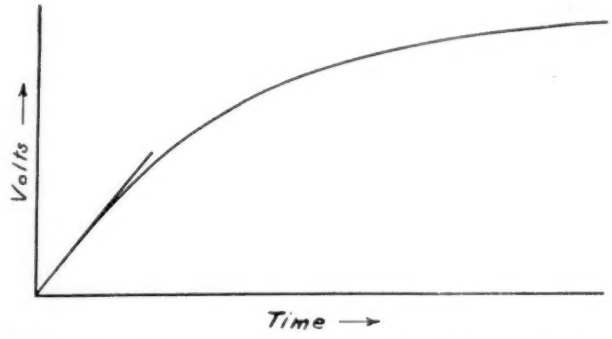
$$\frac{de}{dt} = \frac{E}{RC}. \tag{2}$$

FIG. 1 (*b*).



Transient circuit with a vacuum tube as a switch.

FIG. 2.



Sketch showing the voltage across a condenser as a function of time and the initial slope.

Therefore, for relatively short intervals of time:

$$e = \frac{de}{dt} \cdot t = \frac{Et}{RC}. \tag{3}$$

For values of $e = 0.05E$ and below, the error made in using

equation 3 for equation 1 is less than one in fifty. Thus the time the switch remains closed is given, if the ratio of $\frac{e}{E}$ remains small, by

$$t = e \cdot \frac{RC}{E} . \tag{4}$$

It is then only necessary to measure the voltage e in order to know how long the switch has been closed.

In order to overcome any difficulties caused by erratic contact or sparking at the switch, the switch is replaced by a vacuum tube as is shown in Fig. 1 (*b*). The tube is biased below cut-off by the battery E_C so that no plate current will flow. When the switch S' is closed the bias is removed, and plate current flows to charge up the condenser. The advantages of this method of switching are that the switch S' has only a small voltage impressed on it, the current it must conduct is extremely small, and there is little or no inductance in the circuit. These factors all help make more definite the actual instant at which contact is made or broken. To put a vacuum tube into the circuit is to introduce an additional resistance, the plate resistance of the tube. This must be remembered in using equation (4) since R must be the total resistance of the circuit.

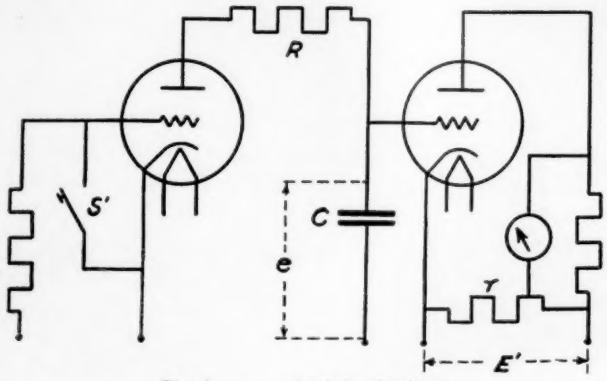
The voltage e of Fig. 1 (*a*) or 1 (*b*) is determined by a vacuum-tube voltmeter. A simplified diagram is shown in Fig. 3. The ammeter in the plate circuit will read a current proportional to the voltage e. The circuit including E' and r is designed to supply a current flowing through the meter in the opposite direction from the plate current so the circuit can be adjusted to a linear portion of the i_p vs. e_g curve of the vacuum tube. To reduce leakage currents it is desirable to make the grid circuit resistance as high as is possible.

A complete diagram of the meter is shown in Fig. 4. The resistance and capacitance of Figs. 1 (*a*) and 1 (*b*) are labeled R and C respectively for identification. Two resistances are included here for two scales on the meter.

Three pairs of terminals are supplied. If it is necessary to know the length of time a circuit remains closed, the circuit is connected to the terminals 5 and 6. When the contact is

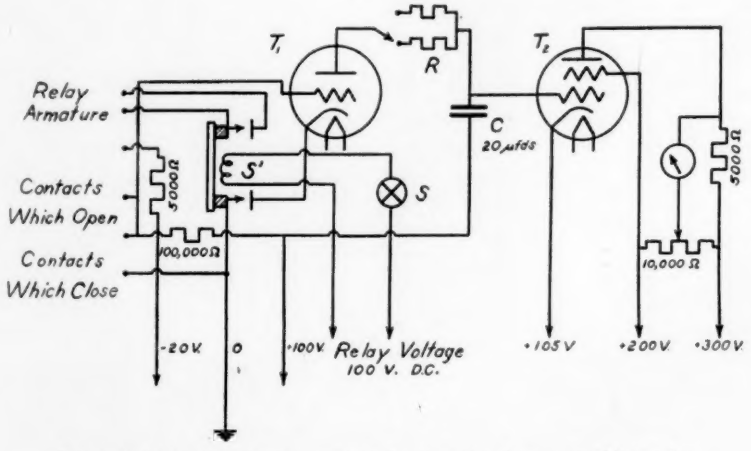
made a short circuit then removes the grid bias from the switching tube and the reading on the meter M is proportional to the length of time the short circuit remains. During this particular operation terminals 3 and 4 must be short-circuited.

FIG. 3.



The elementary circuit for the timer.

FIG. 4.



The circuit of the timer showing contacts for measuring three types of intervals.

To test a relay, the primary circuit with its source of power is connected in series with the terminals 1 and 2. If the relay contacts are to be opened they are connected to terminals 5 and 6, 3 and 4 remaining short-circuited. If the contacts are to close they are connected to 3 and 4.

When ready to make the test the switch labeled S in the timer is closed. This closes the two-pole switch S' which starts the timer and relay at the same instant. The timer is stopped by the closing of the relay contacts. Notice that the time which elapses between the closing of the switches S and S' does not affect the reading. It is only necessary that the two contacts of the switch S' close simultaneously.

CALIBRATION.

There are two methods by which this timer can be calibrated. One is to close a switch for a known period of time by a calibrated contactor and plot the ammeter reading as a function of the time the contact remains closed. Another is to calibrate the vacuum-tube voltmeter separately and calculate the time from the constants of the transient circuit. Both methods were used on the 0.1 and 1.0 second ranges. The other two ranges were calibrated by calculation only.

ACCURACY.

Although there are a number of sources of error in this circuit, none is serious enough to affect the successful operation of the meter.

First, it is essential that the two contacts of the switch S' close simultaneously. If they do not, a constant error is introduced into the readings. However, for intervals of 0.001 second and longer, this requirement does not appear to be very difficult to fulfill.

A more serious error is introduced in the measurement of very short time intervals by the leakage of current through the insulation of the elements of Fig. 1 (*b*). This feature presents no difficulty whatever in the 0.1 and 1.0 second ranges. For use on intervals shorter than the ones here investigated, it may be necessary to use a tube without the conventional socket and base. Also for extremely short intervals a high grade condenser C is necessary, although for the ranges described, paper condensers are quite satisfactory.

Another source of error is the grid current flowing in the Tube T_2. This current gives a charge to the condenser C, and the resulting drift of the grid potential leads to erroneous readings. To overcome this source of error, the condenser is

made large. With 22 mfd. the drift in reading from all causes can be limited to less than one scale-division per minute.

If this drift is made small, the meter will indicate the time interval for a considerable period after the interval has ended; in fact, it will give the sum of a number of successive time intervals.

The reading is proportional to the line voltage. If the line voltage differs from the value at which the calibration is made, the readings must be corrected by multiplying by the ratio of voltages.

The limit of accuracy as determined by the test appears to be the accuracy with which the ammeter in the plate circuit can be read.

CONCLUSIONS

Tests show that this device will read time intervals accurately for full scale deflection of 0.1 and 1.0 second. The constants have been changed to give full scale deflection of 0.01 and 0.001 second, and although these scales were not checked experimentally, there is no reason to doubt that they are any less accurate than the two scales which were checked. The apparatus could be made to read intervals of time much shorter than this, if desired.

ACKNOWLEDGMENTS.

The author wishes to acknowledge the very material assistance rendered by Professor E. B. Rollins and by Mr. Leighton Greenough, a student at Tufts College, in the construction of this device.

Saran—New Vinylidene Chloride Resins.—W. C. GOGGIN (*News Edition American Chemical Society*, Volume 18, No. 21.) The year 1940 has seen many advances in the plastic art—among them the introduction of a group of new thermoplastic resins, based on vinylidene chloride, more commonly known by the trade name "Saran." The product has as its raw materials the almost limitless domestic supplies of crude oil and brine. History is not generally familiar with vinylidene chloride, and it is barely mentioned in a recent comprehensive survey of resinous materials. For some time, however, it has been investigated in a few industrial research laboratories and is now directly or indirectly the subject of some forty patents. Vinylidene chloride is a clear, colorless liquid with a characteristic odor. It boils at 31.7 deg. C. The liquid monomer may be polymerized in a long linear chain by direct linking of the monomer molecules to form an insoluble, white crystalline powder. A wide range of properties may be obtained either by controlling the length of the chain or by using a copolymerizing agent or both. Through a variation in the type and quantity of copolymerizing agents an almost infinite number of resins having widely diversified properties may be obtained. They range from a flexible, moderately soluble material having a softening point around 70 deg. C. to a hard, tough thermoplastic solid with a softening point of at least 180 deg. C. To a greater or lesser degree, these resins exhibit crystallinity of structure. Several applications have already been noted. Saran strands have been used for leaders, trolling lines, and snells by both commercial and sport fishermen. Also an effective use is in transportation seating. Under the severe conditions to which subway car seats are exposed, Saran has stood up remarkably well. Attractive woven bulkhead panels of the material are being used in a number of new airliners. A pure thermoplastic resinous bonding agent, Saran has become an essential ingredient in a new type of abrasive wheel. Promising applications, based on the material's extreme chemical resistance, include extroded tubing and other shapes as well as compression and injection molded articles.

R. H. O.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

SEPARATION OF GASES BY DISTILLATION.

The gas analyst has at his disposal a number of attractive physical methods which may be invoked in time of need to supplement or even replace the various chemical methods. By far the most useful of these is distillation. Unlike most of the other physical methods, distillation can achieve the actual separation and isolation of the various components of a complex mixture. It can accordingly be used for both analysis and purification of gases, and is not limited (as are many physical methods) to binary mixtures. While distillation has been used industrially for a long time, its application to gas mixtures in the laboratory is relatively recent, most of the development having taken place during the last twenty years. In the United States, this development was chiefly in answer to the demand of the natural gas and associated industries, and arose from the necessity of knowing, in so far as possible, the actual composition of complex mixtures of hydrocarbons, a determination that could not be made by the time-honored method of combustion. Methods of distillation have since been applied to various gaseous mixtures, and have recently been used by many industrial research laboratories.

In the March *Journal of Research* (RP1372), Martin Shepherd describes the apparatus and general procedures used at the Bureau for the separation of gases by distillation and rectification at low temperatures. The subject is treated from two viewpoints—analytical separation, and the preparation of pure gases.

DETERMINATIONS OF HYDROGEN IN IRON AND STEEL.

The presence of small amounts of hydrogen as an impurity in iron and steel has been known for a long time. Hydrogen has been blamed for such phenomena as the porosity of ingots,

* Communicated by the Director.

blistering of sheet metal, embrittlement during pickling, and the hardness and brittleness of electrolytic iron, but most of these troubles were ascribed to an "excess" of hydrogen. However, recent experience in the hot working of metals has shown that hydrogen furnishes an outstanding example of the disastrous effects that may result from the presence of surprisingly small amounts of impurities in metals. Less than 0.001 per cent. of hydrogen is believed to be responsible for the defects known as "flakes" in forging steels and as "shatter cracks" in railroad rails.

The available methods for determining minute amounts of hydrogen in steel are discussed in a paper (RP1373) by Vernon C. F. Holm and John G. Thompson which will be published in the *Journal of Research* for March. The authors found that a method which involves vacuum extraction of the hydrogen at 800° C. is rapid and yields reliable results for a variety of materials. Prompt sampling and immediate analysis are advisable because many samples lose hydrogen during storage, even at room temperature. Alloy steels with high chromium contents dissolve more hydrogen and retain it more tenaciously than do simple steels. Hot rolled rods of low-carbon steel, some time after they were rolled, had low and uniform contents with no evidence of segregation of the hydrogen.

PROPERTIES OF CERAMIC TALCOSE WHITEWARE.

Although beautiful and durable pottery and china have been produced for centuries, the ceramic industry is constantly investigating means to provide the consumer with a better and more economical product. More uniformly prepared raw materials and bodies, and more rapid methods for heating, are essential to modern mass production. This entails more closely controlled methods of test and the formulation of compositions adaptable to stream-lined and highly mechanized manufacturing.

To assist the industry in this development, the Bureau constructed an electrically-heated tunnel kiln of semi-commercial size and capable of heating ware on a wide range of temperatures and time cycles. Experiments made in this

kiln are described in a report (RP1371) by R. F. Geller and A. S. Creamer, in the March *Journal of Research*. For the first trials, several hundred specimens of 12 talcose bodies were made, using 3 different forming methods to determine the effects of these methods on the properties of the bodies and on the precision of the data. These data should be of assistance in evaluating the relative merits of the three methods for making laboratory trials. The specimens were then heated in the tunnel kiln on 6 different cycles to determine the effects of relatively rapid schedules of heating and cooling and thereby throwing further light on the possibilities of speeding manufacturing methods.

The results show that deaired bodies are stronger and more uniform than those prepared by hand-wedging.

Pressed specimens are easily prepared, even of bodies having poor workability, but their maturing range and final properties may differ in important respects from those made of plastic masses. Therefore, specimens should not be made by one method to determine the possibilities of a body made commercially by the other method.

Specimens prepared by deairing and extrusion averaged, after heating, 3,100 lb./in.^{2} stronger than the pressed ones and 2,300 lb./in.^{2} stronger than those hand-wedged and extruded, the strength values being expressed as the modulus of rupture in bending.

About one third of the specimens showed the highest strength after the shortest schedule either to cone 4 or to cone 6. The average strength values for all pressed bodies ranged from 5,400 to 9,400 lb./in.^{2} for those heated to cone 4, and from 6,000 to 10,000 lb./in.^{2} for those heated to cone 6. Corresponding values for hand-wedged, extruded bodies ranged from 6,400 to 11,000 lb./in.^{2}, and 7,100 to 12,100 lb./in.^{2}. For deaired, extruded bodies the values ranged from 8,700 to 12,600 lb./in.^{2}, and 9,700 to 13,500 lb./in.^{2}.

Total shrinkage, extensibility, and thermal expansion of any one body were not greatly affected by the various heating cycles. The difference in absorption of specimens heated to cone 4 and to cone 6 was appreciably greater for pressed bodies than for extruded bodies. Several bodies showed an increase in absorption with increase in the length of the

heating cycle, but there is no reason to believe that this is caused by overfiring.

After heating to cone 6 on the 9-hour schedule, all of the bodies were vitrified, but after heating to cone 4 only one pressed body and five extruded bodies were nearly or completely vitrified, that is, they showed less than 1 per cent. absorption.

ACTION OF FROST ON BRICKS.

The resistance of building bricks made from clay or shale to disintegration by frost is known to depend upon their degree of firing. Bricks that are "hard and well burned" are not visibly affected by many years of exposure to severe climates. The eastern part of the United States provides many examples of brick buildings over 200 years old which are in excellent condition. On the other hand, underburned or "salmon" bricks may disintegrate in a few years or even months of exposure to frost action. Laboratory freezing and thawing is impracticable as a routine acceptance test on account of the time required to complete a significant number of cycles. The available means of predicting, with reasonable accuracy, whether or not a given brick will resist frost action therefore depends upon the correlation existing between durability and certain other properties such as strength, absorption, and saturation coefficient. Since all of these properties are themselves affected by degree of firing, satisfactory correlation might be expected.

In order to investigate the relation between certain physical properties of bricks and their resistance to freezing and thawing, a laboratory study was begun at the Bureau in 1930, which included determining compressive and transverse strengths, water absorptions, saturation coefficients and either the number of cycles of freezing and thawing causing failure or the loss in weight after 51 cycles. Most of the bricks were collected as part of the survey made by the Bureau in coöperation with the Common Brick Manufacturers Association of America in 1930. Additional samples were received in 1936 and 1937.

Building Materials and Structures Report BMS60 pre-

sents results of freezing and thawing tests of 3,368 bricks, representing 525 gradings or brands provided by 209 plants, located in 36 States. In addition to the individual results on these bricks, averages for each of 197 additional gradings or samples are given for all results except freezing and thawing. The 197 gradings comprise an additional 1,190 bricks. In addition to numerical data on strengths, absorptions, saturation coefficients, and results of freezing and thawing, information is given concerning the raw materials, methods of manufacturing, and the manufacturer's classification of each sample of bricks. The data are arranged geographically according to producing districts, for each of which a brief summary is provided.

Copies of this publication are obtainable from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 15 cents each.

THE CAUSE AND CURE OF LEAKY MASONRY WALLS.

In tests previously described in this Bulletin, masonry walls, when subjected to conditions simulating an exposure to rain and wind, were found to have widely different degrees of resistance to water penetration. Some of them leaked large quantities of water in less than three minutes, while others withstood a severe test for five days. When leakage occurred it took place largely through openings in the joints. The resistance of the joints to leakage depended mostly upon the method of laying the units, and the walls which were most resistant contained either solidly filled vertical joints or a moisture barrier consisting of a coating of mortar within the wall.

The watertightness of joints also was affected by the suction rate of the bricks (water absorbed when partially immersed for one minute) at time of laying and the working properties or water retentivity of the mortar. In general, it was found necessary to wet highly absorptive bricks before they were laid in order to obtain masonry highly resistant to rain penetration; in fact, the wetter the bricks at time of laying the greater the resistance. Tooling the face joints assisted slightly in reducing leakage, but the permeability

was governed largely by the quality of the joints in the interior of the walls.

Reducing the number of header bricks in walls of common American bond did not have a significant effect upon the water permeability. Walls composed of a facing of low absorptive brick and a backing of highly absorptive brick gave better performances than similar walls constructed entirely of either type of brick. Walls of structural clay tile or hollow concrete block were not highly resistant to rain penetration unless provided with a facing, such as brick masonry or portland cement stucco, or a coating of cement-water paint applied by means of stiff brushes. The performance of cavity walls containing a 2-inch air space indicated that such walls, when properly flashed, would provide an adequate barrier against water penetration.

In summary, the results indicated that the most serviceable masonry walls are likely to be obtained when the suction rate of absorptive bricks is reduced by wetting prior to use and the joints are well filled with mortar having satisfactory working properties.

Openings in the joints of existing brick walls were sealed satisfactorily by: (1) Raking out the joints to a depth of at least ½ inch and repointing; (2) scrubbing a 1 : 1 grout of portland cement and fine sand into the joints by means of small stiff brushes; and (3) applying two coatings of cement-water paint, using stiff fiber brushes. Applications of thin liquid waterproofings retarded the transmission of water by capillarity through the brick but did not seal the relatively large openings in the joints of leaky walls.

CONTROL OF PAPER EXPANSION IN MULTICOLOR LITHOGRAPHY.

The latest development in the treatment of papers to minimize misregister of color prints in offset lithography is essentially the controlled exposure of the paper to correct moisture conditions, an excess of moisture being required.

In the conventional method of conditioning paper for printing, the room atmosphere is blown up around the paper which is hung in a cabinet-like compartment for maximum exposure. The new method employs practically the same equip-

ment and procedure, but water, in measured amounts, is introduced into the air which is blown around the paper. The water is added in the form of a finely-divided spray to the air entering the conditioning machine.

Paper is correctly stabilized for multicolor printing with respect to dimensions when its moisture content is 0.5 to 0.7 per cent. above equilibrium with the humidity of the press-room atmosphere. The new method not only makes possible much faster conditioning than heretofore thought possible, but the moisture content is much more accurately adjusted.

The new method of conditioning has been throughly tested in commercial-scale operation with most satisfactory resulst.

PERMEABILITY OF LEATHER TO WATER VAPOR.

One of the physical properties of leather which contributes greatly to its desirability for use as a shoe and garment material is its ability to allow water vapor to pass through it freely. If the perspiration which the normal human foot exudes is not allowed to evaporate, the foot becomes moist, hot, and uncomfortable. Such conditions favor the development of foot troubles and damage to the leather. Good shoe leather permits the water from the perspiration to pass through it very rapidly.

Robert B. Hobbs, Jr., of the Bureau's Leather Section, has devised a method for measuring the permeability of leather to water vapor. It is similar to a method developed for paper and other sheet materials, but embodies modifications which make it more suitable for leather. This method has been used for materials ranging from 1 to 250 mils in thickness, and having transpiration rates from 5 to 1,500 grams of water per square meter per day. Thus it appears suitable for all kinds of leather.

SODIUM ALUMINATE AND ATMOSPHERIC EFFECTS ON PROPERTIES OF A FLINT CLAY REFRACTORY.

In this investigation, three refractory mixes were studied. Mix A contained 93.55 per cent. Kentucky flint clay and 6.45 per cent. Tyrone plastic clay. The flint clay portion con-

sisted of 55 per cent. which passed the No. 4 and was retained on the No. 10 sieve, and 38.55 per cent. which passed through a No. 100 sieve. Mix B differed from A in that it contained 0.75 per cent. sodium aluminate $(Na_2O \cdot Al_2O_3) \cdot (SiO_2)$. Mix F differed from B in that the flint clay portion consisted of 20 per cent. which passed the No. 4 and was retained on the No. 10 sieve, and 73 per cent. which passed through a No. 20.

Specimens of each of these three mixes were heated to 1400° C. under oxidizing conditions for 25 hours and for 105 hours, and under reducing conditions for 105 hours. Determinations of the CO_2 content were made during each burn for purposes of atmosphere control within the furnace.

The results of tests of five specimens showed: (1) The modulus of elasticity and strength were much lower for specimens heated 25 hours (oxidzing) than when they were heated for 105 hours in either a reducing or an oxidizing atmosphere; (2) The sodium aluminate caused the modulus of elasticity and strength of the specimens to be greatly decreased regardless of atmospheric conditions; (3) The sodium aluminate also caused the extensibility of the specimens to be greatly increased; and (4) The specimens heated for 105 hours under reducing conditions showed both greater strength and modulus of elasticity than did those heated in an oxidizing atmosphere for a similar period of time.

THE FRANKLIN INSTITUTE.

STATED MONTHLY MEETING, MARCH 19, 1941.

The stated monthly meeting for March was held on the evening of Wednesday, March nineteenth, at eight-fifteen o'clock. Mr. W. Chattin Wetherill, Vice-President, presided.

The minutes of the previous meeting were approved as printed in the March issue of the JOURNAL.

The Presiding Officer then called for a report from the Secretary.

In the absence of Dr. Allen, due to illness, the Secretary's report was read by Dr. James Barnes. The following additions to membership were announced:

Sustaining	2
Active	5
Associate	14
Student	35

There being no further business, Mr. Wetherill presented the speaker of the evening, Dr. Edwin H. Armstrong, Professor of Electrical Engineering, Columbia University, who spoke on "Frequency Modulation—Its Applications to Radio Signaling."

The lecturer discussed the history of this very old method of modulation and pointed out its use in a new system of radio transmission. He showed by means of a sound track on a motion picture film the difference between the present method of broadcasting and what might be expected in the future through the use of FM networks. The lecture was illustrated with lantern slides.

Dr. Armstrong addressed a large and interested audience, which adjourned with a rising vote of thanks to the lecturer.

HENRY BUTLER ALLEN,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS

(Abstract of Proceedings of Stated Meeting held Wednesday, March 12, 1941.)

HALL OF THE COMMITTEE,
PHILADELPHIA, MARCH 12, 1941.

MR. COLEMAN SELLERS, 3RD, *in the Chair.*

The following reports were presented for final action:

No. 3079: Floor Construction Element.

This report recommended the award of a Certificate of Merit to Charles William Akers, of Baltimore, Maryland, "In consideration of his invention of the Breeko Floor Block."

No. 3091: Brown Medal.

This report recommended the award of the first Frank P. Brown Medal to Willis Haviland Carrier, of Syracuse, New York, "In recognition of his outstanding achievements in the field of Heating, Ventilation and Air Conditioning."

No. 3092: Levy Medal.

This report recommended the award of Louis E. Levy Medals, jointly, to John M. Lessells and Charles W. MacGregor, of the Massachusetts Institute of Technology, Cambridge, Massachusetts, for their paper entitled "Combined Stress Experiments on a Nickel-Chrome-Molybdenum Steel," which appeared in the August issue of the Journal of The Franklin Institute for 1940.

At the January 8, 1941, Stated Meeting, the following report was presented for final action:

No. 3082: High-Speed Motion Picture Apparatus.

This report recommended the award of a Howard N. Potts Medal to Harold E. Edgerton, of Cambridge, Massachusetts, "In consideration of his invention of, and, with the aid of his assistants, his development of a high-speed motion picture camera with a new type of illumination control, which has increased knowledge in the fields of pure and applied science."

This recommendation was advertised in the February issue of the JOURNAL OF THE FRANKLIN INSTITUTE and the advertisement expired without the receipt of objection.

JOHN FRAZER,
Secretary to Committee.

LIBRARY NOTES.

Photostat Service. Photostat prints of any material in the collections can be supplied on request. Orders received in the morning are filled the same day. The average cost for a print 9 × 14 inches is forty cents.

The library and reading room are open on Mondays, Tuesdays, Fridays and Saturdays from nine o'clock A.M. until five o'clock P.M., Wednesdays and Thursdays two until ten o'clock P.M.

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NOTES FROM THE BARTOL RESEARCH FOUNDATION.

PERIOD OF PHOTON EMISSION IN A COUNTER DISCHARGE.*

BY

W. E. RAMSEY.

That the ionization in a Geiger-Mueller counter takes place in a very early stage of the discharge and before the wire has changed appreciably in potential is an essential element in the mechanism proposed by C. G. Montgomery and D. D. Montgomery.[1] The investigation to be described here leaves no doubt that photon emission in a counter takes place during a short time interval following the initiation of the discharge, and that few, if any, photons are emitted during the greater part of the time required by the wire to reach its maximum negative potential.

Two counters, 1 and 2, Fig. 1, share a common glass envelope. Although the counter wires are carefully shielded electrostatically from each other by S, photons emitted by one may pass to the other through holes A and B in the counter cylinders. This photon transmission is controlled by the plunger P which may be moved to expose any desired portion of the transmitting and receiving areas A and B. The voltage pulses from these counters are applied to a coincidence circuit. The resolving time of this circuit may be varied from $< 10^{-7}$ second to 10^{-3} second and special care is exercised to prevent this variation from influencing in any way the discharge phenomena in the counters themselves. These resolving times were determined experimentally employing a pulse generator previously described.[2] With P in such a position as to screen the openings A and B from each other, no coincidences are observed. As A and B are exposed

* Reprinted from *The Physical Review*, **58**, 476 (1940).

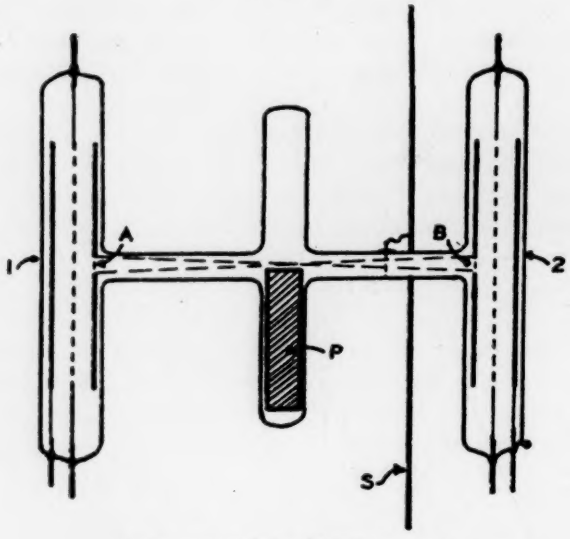
[1] C. S. Montgomery and D. D. Montgomery, *Phys. Rev.*, **57**, 1030 (1940).

[2] C. S. Montgomery, W. E. Ramsey, D. B. Cowie and D. D. Montgomery, *Phys. Rev.*, **56**, 635 (1939).

to each other by moving P, coincidences appear, and a point is reached where all discharges in one counter are accompanied by discharges in the other.

In Fig. 2, representing an experiment to be called A, the coincident rate is plotted as a function of resolving time for the case where P was so placed that 90 per cent. of the discharges in one counter were accompanied by discharges in the other (resolving time 2.0×10^{-4} second). There is no observable increase in the number of coincidences between one

FIG. 1.



Arrangement of Geiger-Mueller counters.

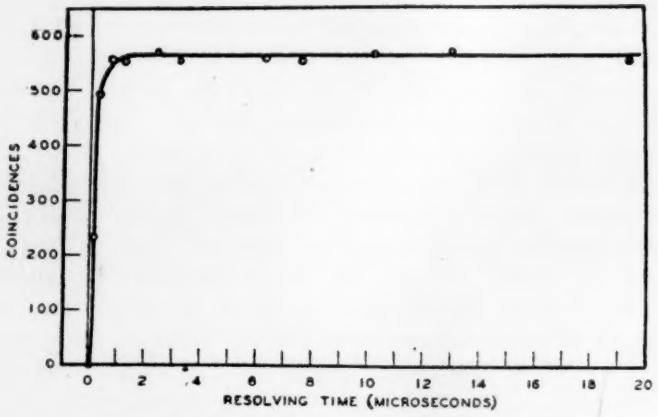
and twenty microseconds. In another experiment (experiment B) where P was in such a position that the probability of one counter setting off the other in a time of 2.0×10^{-4} second was 0.42, there was an increase in the number of coincidences between one and twenty microseconds of only (3.1 ± 3.6) per cent.

Measurements by the author [3] on a counter of the diameter and pressure used in these experiments indicate that the counter wire experiences one-half of its potential change in

[3] W. E. Ramsey, *Phys. Rev.*, **57**, 1022 (1940).

the interval between one and twenty microseconds. If the number of photons emitted by a counter in a given time interval were proportional to the change of potential of the wire during the interval, we should expect an increase of the coincidence rate between one and twenty microseconds which amounts to 20 per cent. for the case A, and 60 per cent. (or 20 times that found) for the case B. It is safe to assume that

FIG. 2.



Relation between coincidence rate and resolving time in experiment A.

any condition, such as has been formerly assumed in counter discharge theory, in which measurable changes of wire potential were assumed to be accompanied by measurable photon emission, is at variance with the present observations. These experiments are, however, in agreement with the discharge mechanism formulated by C. G. Montgomery and D. D. Montgomery. The lags which actually occur are to be expected, and can be accounted for by electron capture in the gas. This phenomenon has been reported elsewhere.[2,4]

[4] J. V. Dunworth, *Nature*, **144**, 152 (1939).

NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION.

The Effect of Heat Treatment and High-Speed Centrifuging on Type II Anti-Pneumococcus Horse Serum.—LAURA E. KREJCI, LOUIS DESPAIN SMITH AND T. J. DIETZ. The electrophoretic analysis of horse serum which has been heated at temperatures between 50° and 70° for periods of time up to thirty minutes was recently reported by van der Scheer, Wyckoff and Clarke (*Journal of Immunology*, **40**, 39, 1941). The most striking result of the heating is the progressive formation of a new colloidal component C of about the same mobility as beta globulin. This is produced largely at the expense of the globulins, but after prolonged or intense heating includes considerable amounts of albumin. In immune sera it forms at the expense of the antibody-containing T and gamma globulins.

A similar observation has been made in this laboratory on a sample of anti-pneumococcus horse serum.[1] At the time the scale method of Lamm (Tiselius and Horsfall, *The Journal of Experimental Medicine*, **69**, 83, 1939) was being used to record the migration, and after the completion of the series a systematic error was discovered which had impaired the accuracy of the scale diagrams. Strictly quantitative conclusions cannot be drawn from the data, but since the production of the C-component has now been confirmed by the more extended observations of van der Scheer, Wyckoff and Clarke, it seems worth while to report briefly the additional findings which were sufficiently definite to be conclusive in spite of the optical error.[2]

[1] The sample of anti-pneumococcus horse serum used in this study did not lose its capacity to precipitate with type-specific polysaccharide on heating at 65° C. for periods up to thirty minutes. Only two samples of serum, out of nine examined, retained precipitability after being subjected to this temperature for ten minutes.

[2] The error was caused by an uncorrected objective. In the peripheral portions of the lens, through which the light from the steepest gradients passed, the magnification was somewhat greater than at the center. As a result the apparent scale line displacements differed from the true displacements in a complicated fashion, but in general were too great for the higher gradients.

Type II anti-pneumococcus horse serum provided by the National Drug Company was heated at 64–65° C. for ten minutes and immediately chilled, then centrifuged for three hours at 31,000 r.p.m. in a Beams quantity centrifuge; a sample of unheated serum was included in the centrifuge as a control. The opalescence caused by the heating was deposited as a clear gelatinous button in the centrifuge tubes. The centrifuged supernatant fluids as well as the uncentrifuged controls, were then diluted with three volumes of a buffer solution of pH 8 which was 0.02 M with respect to total phosphates and 0.15 M in sodium chloride. The gelatinous button obtained by centrifuging was dried by the lyophil process and redispersed with the sonic oscillator in a volume of buffer equal to one and one-half times the original serum volume; the solution remained strongly opalescent, but contained no insoluble residue. All solutions were dialyzed against large volumes of buffer before electrophoresis in standard Tiselius equipment (Tiselius, *Transactions of the Faraday Society*, **33**, 524, 1937; *Biochemical Journal*, **31**, 1464, 1937).

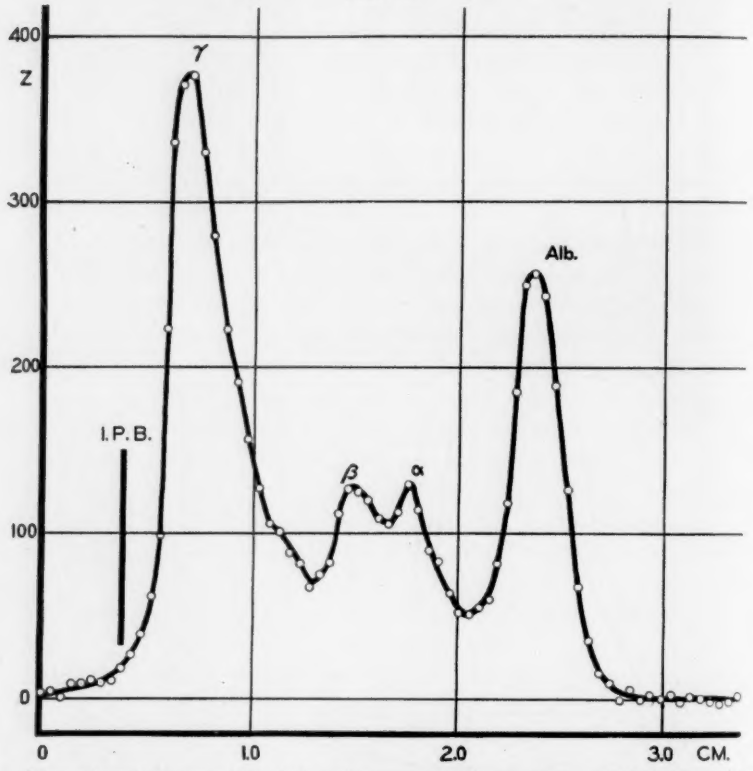
The electrophoretic diagrams are reproduced in Fig. 1 and in Fig. 2. Fig. 1*a* represents the unheated serum, and Fig. 1*b* unheated serum from which the antibody had been removed by precipitation with the homologous polysaccharide; by comparison of the diagrams it can be seen that the antibody formed part of the gamma globulin. High-speed centrifuging of the unheated serum led to a partial impoverishment of the gamma globulin, and reduced by about thirty per cent the antibody content of the upper two-thirds of the centrifuged sample, as shown by precipitation tests.

Heating of the serum caused the formation of a moderate amount of the C-component (Fig. 2*a*), presumably at the expense of the antibody; this point was not confirmed immunologically. The supernatant fluid obtained by high-speed centrifuging differed from the uncentrifuged heated serum chiefly in the much lower relative concentration of gamma globulin (2*b*); since it contained no specifically precipitable protein, removal of the antibody by the centrifuging must have been largely responsible for this difference. The redispersed sediment, however, consisted not of gamma globulin

but of practically pure C-component (Fig. 2*c*); most of this C-component was specifically precipitable by the homologous polysaccharide (Fig. 2*d*).

Quantitative immunological tests by the method of Heidelberger on a separate sample of the same serum demonstrated

FIG. 1*a*.



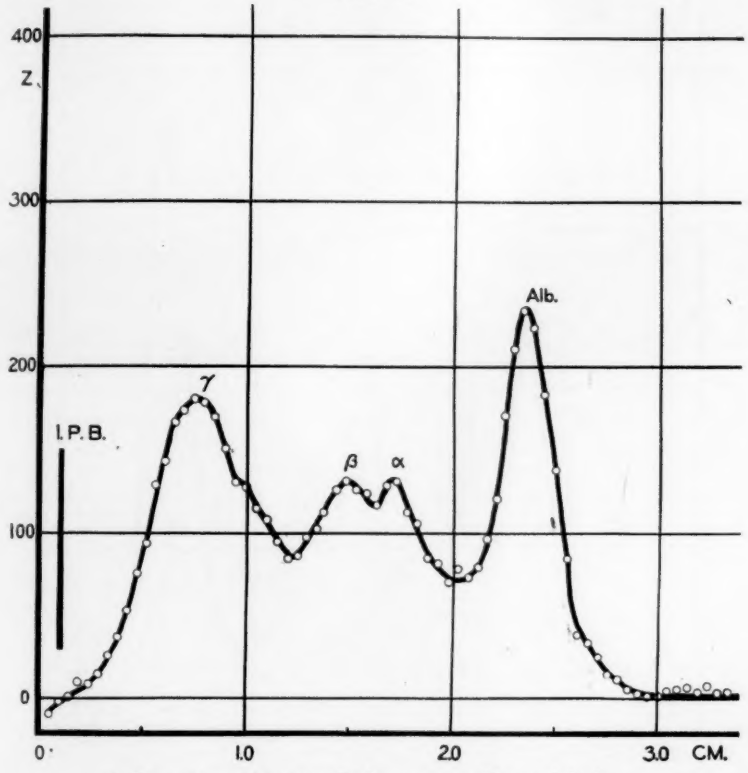
Electrophoretic diagrams of Type II anti-pneumococcus horse serum, unheated; descending boundaries, three hours' migration. I. P. B. indicates the initial position of the boundary. *a*. Untreated serum.

that heated serum contained about 70% more specifically precipitable nitrogen than unheated serum, and that the sediment contained about three times as much as the volume of unheated serum from which it had been prepared (Table I); presumably this can be attributed to the inclusion of immunologically inert protein in the antibody aggregation

product. However, the capacity to combine with polysaccharide was slightly diminished, and the ability of the sediment to protect mice against pneumonic infection was reduced from 500 units to 26 units.[3]

The residual C-component in the redispersed sediment

FIG. 1*b*.



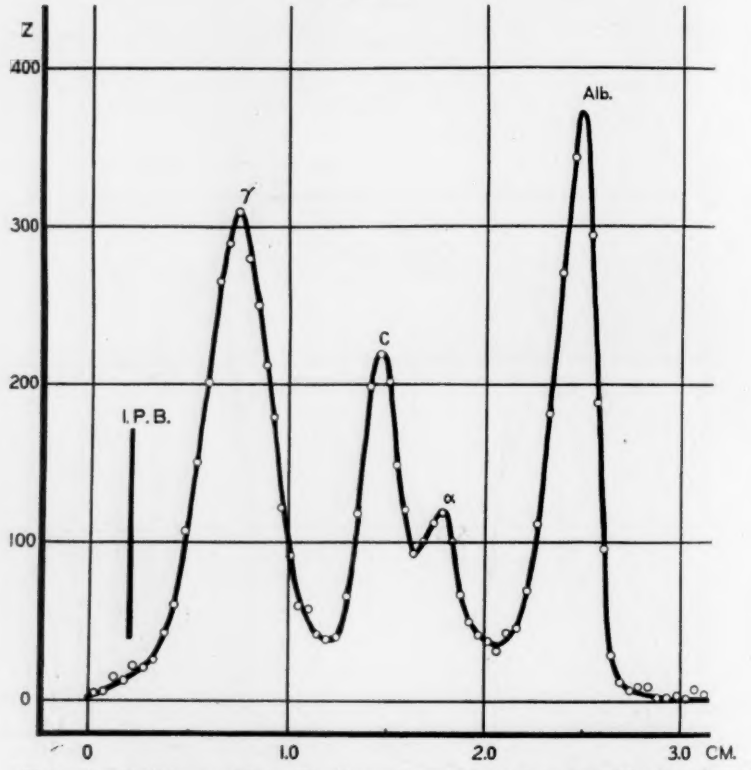
b. Serum from which the antibody was removed by precipitation with the homologous polysaccharide.

after removal of the specifically precipitable protein (Fig. 2*d*) and in the centrifuged supernatant fluid (Fig. 2*b*) may be an

[3] The mouse protection tests were carried out at the antitoxin laboratory of the National Drug Company. The data on the precipitable nitrogen and the mouse protective action were reported by Dietz, Smith, Krejci and Jennings to the Division of Biological Chemistry at the 100th meeting of the American Chemical Society, Boston, September 15, 1939.

aggregation product of inert protein alone. That in the centrifuged supernatant fluid (Fig. 2*b*) does not represent the same material as the C-component in the heated serum (Fig. 2*a*), in spite of the similarity in areas; the latter was strongly opalescent and was undoubtedly removed during centrifuging.

FIG. 2*a*.



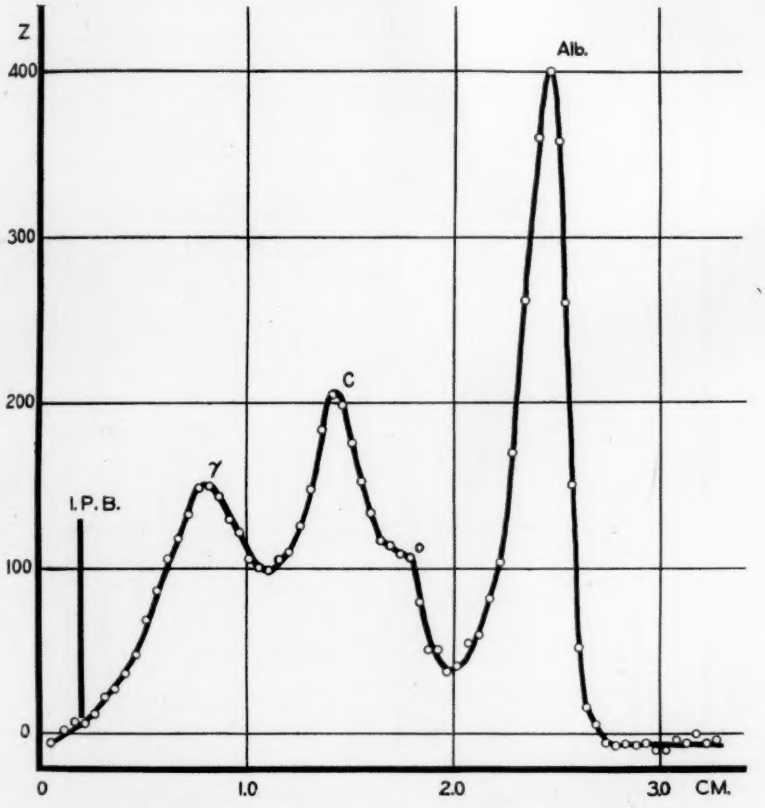
Electrophoretic diagrams of Type II anti-pneumococcus horse serum heated for ten minutes at 64–65° C.; ascending boundaries, three hours' migration. I. P. B. indicates the initial position of the boundary. *a*. Before centrifuging.

The C-component in the centrifuged supernatant fluid, like most of the C-component in the redispersed sediment, was doubtless formed during centrifuging. It displayed somewhat greater boundary spreading than the C-component present before centrifuging, probably because of the combined effects of its smaller particle size, and consequent greater

diffusion, and the heterogeneity of charge which van der Scheer, Wyckoff and Clarke have emphasized is characteristic of the C-component.

Heterogeneity of the C-component with respect to charge was observed in this laboratory also. After prolonged electro-

FIG. 2*b*.



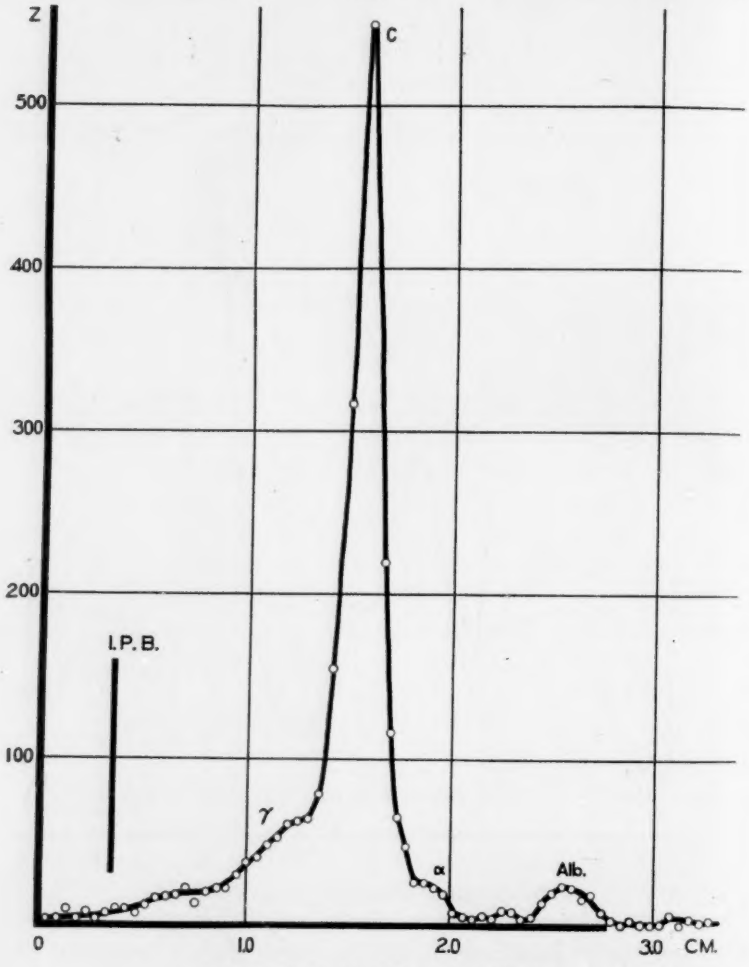
b. Supernatant fluid obtained by high-speed centrifuging.

phoresis the C-component of the redispersed sediment was resolved into two maxima (Fig. 3).

The data indicate that the formation of the C-component includes at least two reactions: heat denaturation of the protein, an intramolecular reaction which appears to be accom-

panied by very little alteration in mobility, and the subsequent aggregation of the denatured molecules, which results in a pronounced change of mobility. For the antibody at least

FIG. 2c.

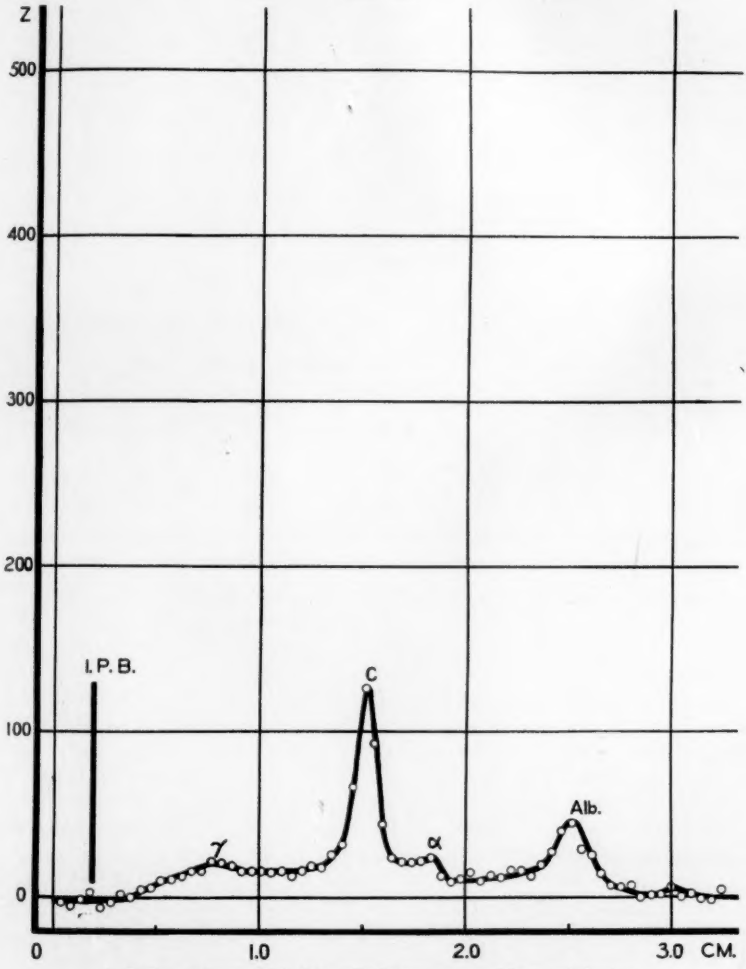


c. Sediment obtained by high-speed centrifuging.

the primary reaction must have been carried to completion during the comparatively short period of heating, because ultimately all of it was obtained as C-component. On the

other hand, the aggregation, which depends on a collision mechanism, was repressed before completion by the reduction in temperature, but was given an opportunity to continue

FIG. 2*d*.



d. Sediment from which the antibody was removed by precipitation with the homologous polysaccharide.

during centrifuging because of the increased collision frequency in the more concentrated mass of solution which gradually accumulated along the peripheral edge of the angled

TABLE I.

Antiserum		Control	Protein Concentration		Concentration Factor
Heated 65° C.—10 min.	Heated 60° C.—15 min.		Total	Precipitable	
Uncentrifuged control			7.8[1] 6.8[2]*	1.2[2]	1.9
	Uncentrifuged control		7.6 7.4	0.7	1.0
		Uncentrifuged control	7.6 7.4	0.7	1.0
Centrifuged supernatant 1.			4.8 4.6	0.0	0.0
	Centrifuged supernatant 1.		5.8 5.4	0.1	0.2
		Centrifuged supernatant 1.	6.6 6.2	0.5	0.8
Centrifuged supernatant 2.			1.2 1.1	0.0	0.0
	Centrifuged supernatant 2.		1.0 1.0	0.06	0.6
		Centrifuged supernatant 2.	1.3 1.3	0.1	0.8
Centrifuged sediment			3.7 3.5	2.1	6.3
	Centrifuged sediment		2.0 1.9	0.8	4.4
		Centrifuged sediment	0.8 0.8	0.1	1.3

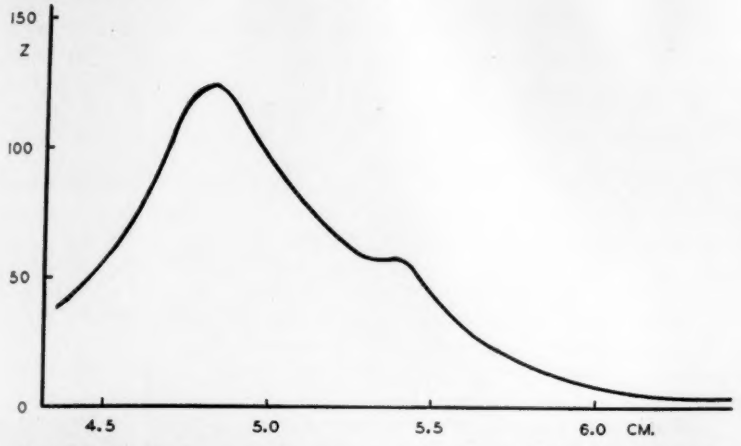
[1] —by refractive index. [2] —by micro-Kjeldahl. * —doubtful.

Description of fractions: The sera were centrifuged at 100,000 × *g* for three hours. About 5/6 of each centrifuged sample was carefully pipetted off as supernatant fluid I. The remaining sediment was dissolved in phosphate buffered physiological saline (pH = 7.4) and brought to the original volume; this solution was carried through a second centrifugation at 100,000 × *g* for three hours. About 5/6 of the supernatant fluid of each sample was pipetted off as supernatant fluid 2. The remaining sediment was dissolved in buffered physiological saline as before and designated the sediment fraction. Greater changes were produced by a short period of heating at the higher temperature than by the longer period of heating at the lower temperature; the high temperature coefficient which this trend indicates is characteristic of protein reactions in general.

tube. It appears that beyond a certain point increased time of heating has no further effect on the primary reaction and serves only to promote the second.

The results suggest that high-speed centrifuging may hold some promise in the study of certain types of protein denaturation as a means of enhancing secondary collision effects in order to differentiate them from the primary reaction.

FIG. 3.



Electrophoretic diagram of the C-component of the sediment obtained by high-speed centrifuging of the heated serum; descending boundary, 13½ hours' migration. The abscissa represents the actual distance migrated.

SUMMARY

Electrophoretic analysis of antiserum heated for ten minutes at 64–65° C. indicated the formation of a small quantity of C-component. High-speed centrifuging removed the antibody completely from the supernatant fluid; on the electrophoretic diagrams this was evident as a pronounced reduction of the gamma fraction. On redispersion, the gelatinous precipitate of antibody deposited during centrifuging was found to consist not of gamma globulin but of C-component. The significance of these results is discussed.

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